



TITLE:

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CITATION:

Tai, Akiko. A Study on the Pollen Stratigraphy of the Osaka Group, Pliocene-Pleistocene Deposits in the Osaka Basin. Memoirs of the Faculty of Science, Kyoto University. Series of geology and mineralogy 1973, 39(2): 123-165

ISSUE DATE:

1973-02-28

URL:

<http://hdl.handle.net/2433/186585>

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A Study on the Pollen Stratigraphy of the Ôsaka Group, Pliocene-Pleistocene Deposits in the Ôsaka Basin

By

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(Received Sept. 30, 1972)

Abstract

From the view point of the pollen stratigraphy, the Osaka group, the typical Pliocene-Pleistocene deposits distributed in the Kinki district, Central Japan, is divided into *Metasequoia* Zone below and *Fagus* Zone above. Those divisions correspond with the stratigraphical units, that is, the Lower formation and the Upper formation of the Osaka group respectively. The former zone is characterized by the decrease of the Tertiary type tree pollen and the increase of the coniferous tree pollen which are present in Japanese Islands, and further it is subdivided into A-D subzones ascendingly. The marine beds of the latter are characterized by the high percentage of *Fagus* pollen, and a spectrum obtained from the fresh water bed shows the pollen composition consisting of cool-temperate to cold climate. Basing upon the compositional oscillation of the pollen diagram in regard to lithofacies changes, *Fagus* zone is subdivided into E-H subzones. As to the climatic changes, the first distinct cool phase is supposed to be at the boundary between B and C subzones. The climatic oscillations are assumed to occur once or twice in each subzone of which oscillation of F subzone is most distinct.

During the advance from A to H subzones, the shift of the warm forest seems to have began from the mixed-forest composed of the Tertiary type coniferous trees and variegated broad-leaved trees (especially represented by high percentage of *Quercus* pollen) to the single tree forest such as *Cryptomeria* or *Fagus* forest. At the time of H subzone, the forest which is composed of evergreen *Quercus* accompanied with warm-temperate trees (*Podocarpus*, *Paliurus*, etc.) appeared in some parts, probably as the secondary forest. As to *Fagus*, it may be probable that the differentiation of warm-temperate and cool-temperate types took place at least at the time of G and H subzones.

I. Introduction

The analysis of the history of the floras since the Late Pliocene provides important and attractive problems in the Quaternary research. In Japan, it was first that Miki (1948) made a synoptical work with the description of the Pliocene and Pleistocene plant remains found from the Kinki district, Central Japan, to which great attention was given. In recent years numerous data on the stratigraphy and the fossil records of the Osaka group have been obtained. Due to those important and manifold informations, it becomes possible to discuss the vegetational sequence in some detail.

Besides the investigations on the stratigraphical succession of the Osaka group

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("OSAKA GROUP" RESEARCH GROUP, 1951; ITIHARA *et al.* 1955; ITIHARA, 1960), the combination of the stratigraphy and the flora has been made by many authors (HUZITA, 1954; ITIHARA, 1960; 1961; ITIHARA *et al.*, 1955; 1965; KOKAWA, 1961; NIREI, 1968). But, in order to clarify the outline of floral changes more precisely, the pollen analytical study has been requisite.

The palynological study on the Osaka group and its correlatives has been exploited by SHIMAKURA (1959; 1964; 1965), and the study of the pollen stratigraphy has been promoted by ONISHI (1968), ONISHI and NASU (1968), NASU (1970), and the present writer (TAI, 1963; 1964; 1966; 1969; 1970 a, b). In this paper the writer wishes to present a standard pollen stratigraphy of the Osaka group and to give general aspect on the floral change in the Kinki district since the Late Pliocene.

Recently, as to the Osaka group and its correlatives, the stratigraphical, paleontological, paleomagnetic and radiometric studies have been carried out under the cooperative works of 1966–68 subsidized by the fund of the Ministry of Education, and the results have been summarized by many authors (TAKETSUZI and ITIHARA, 1967; KAMEI, 1969; KAMEI and SETOGUCHI, 1970; ISHIDA *et al.*, 1969; NISHIMURA, 1969; NISHIMURA and SASAJIMA, 1970; ITIHARA and KAMEI, 1970). On the basis of the above-mentioned results in addition to the writers palynological study, the present writer will give her considerations on the following subjects:

1) The pollen zones of the Osaka group. 2) The tree-kind analysis presumed from the combination of fossil pollen and plant remains. 3) The floral and climatic changes during the Late Pliocene and the Early Pleistocene.

II. Method and Materials

Materials

Localities and stratigraphical horizons from which the materials were taken are shown in Figs. 1—5, respectively. Materials, about 500 g each, were sampled at the vertical interval of 20 or 10 cm in the type section (Tsuchimaru, Senriyama, Hirakata and Machikaneyama). Skeleton diagrams are prepared from samples of 40 cm vertical interval. The samples of the intervening position were also examined if necessary.

Procedure of preparation

To prepare the samples, the writer used the SHIMAKURA's method (SHIMAKURA, 1956) and its improved one (TAI, 1969). Namely, the following procedures were carried out in usual manner. Dispersion of the sample by 10 percent (aqueous solution of) KOH → extraction of the colloidal clay by washing → preparation by mixed acid, *i.e.*, HCl:HNO₃:H₂O (1:1:1) → extraction of the soluble substances

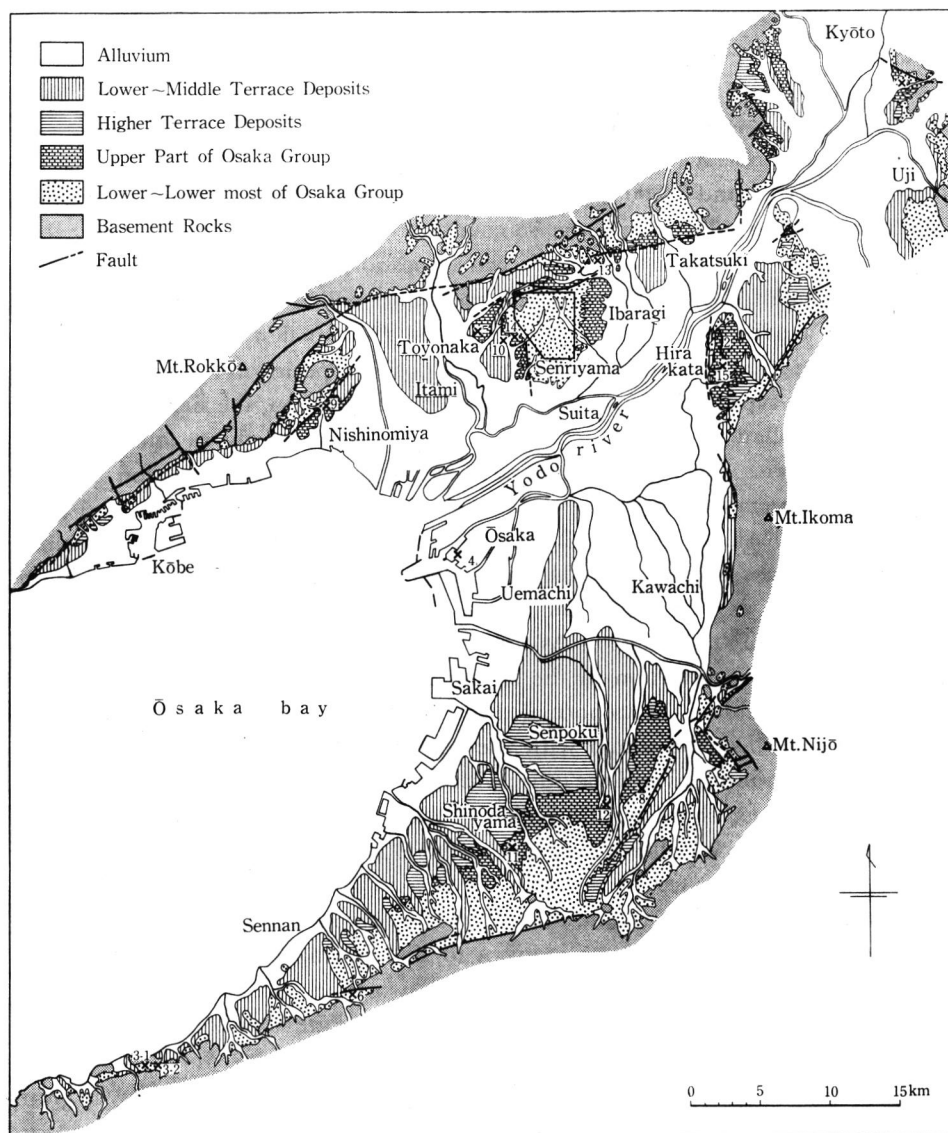


Fig. 1. The locality map showing the sampling sites (geological map according to ITIHARA, 1966).
 1: Fukakusa, 2: Hirakata, 3-1: Tannowa I, 3-2: Tannowa II, 4: OD-1 (Tanaka motomachi, Minato-ku, Osaka City), 5: Machikaneyama, 6: Tsuchimaru-Oike, 7: Central part of Senriyama Hills, 8: Gokenya, 9: Manzidani, 10: Toyonaka, 11: Komyo-ike, 12: Imakuma, 13: Fukakusa, 14: Mitsuike, 15: Bussharito, Hirakata.

in alkali by 10 percent (aqueous solution of) KOH →condensation of waste plant residue by centrifuging →extraction of SiO₂ by HF →acetolysis preparation →mounting in glycerol jelly.

Indication of analytical results

Microscopic observation of the pollen grains was done under the magnification of 400 x or 600 x, and 1,000 x (immersed in oil) if necessary. Except for *Alnus*, the number of the pollen grains was so counted that the number of the tree pollen exceeded 200, but in some samples, it was impossible to count the exact number. In several samples, the frequency distribution of the pollen grain size was estimated for *Tsuga*, Taxodiaceae type, *Quercus*, *Picea* and *Fagus*-pollen. The size of about 50–100 pollen grains was measured for each pollen type in every sample. As to the distribution type of the grain size and the modal position, the simplified indication of each pollen type treated here will be described briefly as follows.

Tsuga pollen: *Tsuga* pollen having normal grain size distribution has the evaluation of the mode which is grouped into three, that is, 60 μ -, 70 μ - and 80 μ -groups (TAI, 1964). Therefore, in the present paper, *Tsuga* pollen is classified as *Tsuga* K, *Tsuga* S and *Tsuga* D, respectively, and the intermediate types are indicated by like as *Tsuga* S-K and *Tsuga* D-S.

Picea pollen (TAI, 1963): As the pollen grain of this sort is apt to receive breaking down and distortion in the sediments, the frequency distribution curve of the grain size seldom shows normal distribution. The distribution is separated into two groups, *i.e.*, the group with the center of the distribution being below 100 μ (B type distribution) and the other with that above 100 μ (A type distribution). In the latter group, characteristic pollen of *Picea* A are found.

Taxodiaceae type pollen (TAI, 1963, 1966): The evaluation of the mode is separable into two parts at the point of 30 μ in grain size. Taxodiaceae type pollen which show a larger mode than 30 μ is called as Taxodiaceae II type and the name of Taxodiaceae I type is given to that having the smaller mode than 30 μ . Furthermore, Type I is separated into two types, *i.e.*, I-a type of normal distribution, and I-b type which shows an intermediate type between I-a type and II type.

Fagus pollen (TAI, 1969): This pollen group includes two types in grain size distribution, *i.e.*, the type in which the evaluation of the mode occupies in the vicinity of 35–36 μ and the type which has the evaluation in the vicinity of 40 μ . The former is called *Fagus*-S, and the latter is called *Fagus*-L.

Quercus pollen (TAI, 1963): Of those whose frequency distribution of the grain size shows normal curve, *Quercus* pollen has the evaluation of the mode separable into two groups, *i.e.*, the one distributed in the vicinity of 22 to 24 μ and the other above 28 μ . The former is called *Quercus* E and the latter is called

Quercus D. The intermediate type is called *Quercus* D-E.

Some of the above-mentioned fossil pollen grains corresponding to living species are given in Table 1.

III. Stratigraphy and the pollen analyses of Osaka Group

Stratigraphy

The Osaka group distributed in the Setouchi Geological Province is a product of the deposition during the Late Pliocene and Early Pleistocene. In many places

Table 1. Grain sizes of pollen from living tree and correlative fossil pollen.

1-a. Coniferous, tree, 1-b. Broad-leaved tree.

After J. UENO (1951, 1957, 1958), VAN. CAMPO (1950), M. IKUSE (1956), J. NAKAMURA (1956), M. TAKEOKA (1959), and A. TAI (1969).

Tab. 1-a

Species	Grain size of pollen	The type of fossil pollen
<i>Picea jezoensis</i> var. <i>hondoensis</i>	?	Picea (B)
<i>Picea jezoensis</i>	80 × 43 × 47 68 × 82 78	
<i>Picea bicolor</i>	73 × 41 × 46 73	
<i>Picea koyamai</i>	85 × 47 × 47 85	
<i>Picea maximowiczii</i>	?	
<i>Picea polita</i>	90 × 50 × 52 90	
<i>Picea koribai</i>	?	Picea (A)
<i>Tsuga diversifolia</i>	88 78–85 × 78–85 71 82 (mode)	Tsuga-D
<i>Tsuga sieboldii</i>	69 66 72 (mode)	Tsuga-S
<i>Tsuga oblonga</i>	?	Tsuga-K ?
<i>Metasequoia disticha</i>	19–28	Taxodiaceae type I
<i>Metasequoia japonica</i>	?	
<i>Sequoia sempervirens</i>	33–42	Taxodiaceae type II
<i>Glyptostrobus pensilis</i>	36–43 × 38–46 28–34 27–29 × 30–33	
<i>Cryptomeria japonica</i>	24–32 30–33 × 34–39	

Tab. 1-b

Species	Grain size of pollen	The type of fossil pollen
<i>Quercus glauca</i>	19–19.5 × 21.5–23 21.60 (mode) 22.20 (mode)	Quercus-E
<i>Quercus gilva</i>	24.00 (mode) 22.20 (mode)	
<i>Quercus phyllyreoides</i>	21.96 (mode) 20–23 × 23–25.5 22.20 (mode)	
<i>Quercus rubroidea</i>	?	?
<i>Quercus hikitai</i>	?	?
<i>Quercus mongolica</i> var. <i>grosseserrata</i>	28.80 (mode) 23–24.5 × 27.5–30	Quercus-D
<i>Quercus serrata</i>	28.80 (mode) 22–23 × 24.5–27 25.90 (mode)	
<i>Quercus variabilis</i>	31.20 (mode) 29–29.5 × 32–34	
<i>Quercus acutissima</i>	29.60 (mode) 36.00 (mode) 29 × 37.5–39 29.60 (mode)	
<i>Quercus aliena</i>	?	
<i>Fagus japonica</i>	29 × 31–32.5	Fagus-S
<i>Fagus crenata</i>	39–40 × 45.5–47 39.97 ± 0.23	Fagus-L
<i>Fagus hayatae</i>	?	?
<i>Fagus ferruginea</i>	?	
<i>Fagus microcarpa</i>	?	

the hills in the vicinity of the Osaka Area, such as, Senriyama (ITIYARA *et al.*, 1955; ITIYARA, 1960; 1961, TAKETSUZI and ITIYARA, 1967), Nishinomiya (HUZITA, 1954; ITIYARA *et al.*, 1965), Hirakata (TAKAYA and ITIYARA, 1961), Fukakusa (FUKAKUSA RESEARCH GROUP, 1962), Senpoku (ITIYARA *et al.*, 1965), Sennan (HARATA *et al.*, 1963), *etc.* consist mainly of the Osaka group. On the other hand, in the plain region (OSAKA CITY, 1964; ITIYARA and KAMEI, 1970; ITIYARA, 1970), the Osaka group subsided tectonically and, is overlain by Recent alluvial deposits. The main components of the group are gravels, sands and clays of fresh-water in which ten layers or more of tuff are intercalated as good key beds. Furthermore, a large number of plant remains have also been found in the group.

The Osaka group is divided into the upper and the lower parts by the characteristic tuff layer called the "Azuki" tuff. In the hilly regions are discriminated

three marine clay beds in the lower part and six in the upper part. For conveniences sake in this paper, the marine clay beds are called as Ma0, Ma1, Ma2,... Ma9 in ascending order and the fresh-water deposits found between the marine beds are called as FrO-1, Fr1-2, ..., (TAI, 1966). The standard succession of the Osaka group is established in the Senriyama Hills, and it has been known that the tuff layers and the marine clay beds there provide a good key for the correlation of that succession with the equivalent deposits found in other districts.

A part of the Osaka group in the Sennan district yields a large number of Tertiary type plant remains at a certain horizon and this part is regarded to be the Lowermost part of the Osaka group (ITIYARA, 1960, 1961).

Apart from the hilly region, the Osaka group has also been ascertained in the Osaka plain by deep boring (ITIYARA and KAMEI, 1970; OSAKA CITY, 1964). In the boring cores, tuff layers and marine clay beds which are equivalent to those of the standard stratigraphical succession could be recognized. Although thirteen marine clay beds are found in the boring cores, it is open to doubt whether the deposits above the Ma9, and those below the depth of 700 m belong to the members of the Osaka group or not.

The standard pollen succession

On the basis of the pollen analyses, the present writer divided the Osaka group in Fukakusa and Hirakata districts into two zones, *i.e.*, *Metasequoia* zone and *Fagus* zone, and furthermore, into several subzones (TAI, 1964, 1963). In view of the subsequent informations obtained by the pollen analyses of other areas, it becomes necessary to revise the former zonation to some extent. In order to establish the standard pollen succession, the more precise data obtained from the following localities have to be added to the former results.

- a. Tsuchimaru-Oike (Izumisano City, Osaka Prefecture), (TAI, 1970-a). Lowermost part of the Osaka group (Fig. 2-a).
- b. Central part of the Senriyama Hills (Toyonaka City and Suita City, Osaka Prefecture), (TAI, 1970-b). Lowermost and lower parts of the Osaka group (from Shimakumayama tuff horizon to Azuki tuff horizon in Ma3) (Fig. 2-b).
- c. Hirakata Hill (Hirakata City, Osaka Prefecture), (TAI, 1963, 1964). The lower and the upper parts of the Osaka group. (Ma2-Ma8) (Fig. 2-b).
- d. Machikaneyama, north-western part of the Senriyama Hills. (Toyonaka City, Osaka Prefecture), (TAI, 1969). The upper part of the Osaka group. (Ma7-Ma9) (Fig. 2-b).

From the view point of the pollen succession, the Osaka group in the hilly regions can be subdivided into eight subzones, *i.e.*, A,B,...,H, in ascending order. For the zonal classification the disappearance of the Tertiary type tree pollen and the characteristics of the pollen assemblage in each horizon were available

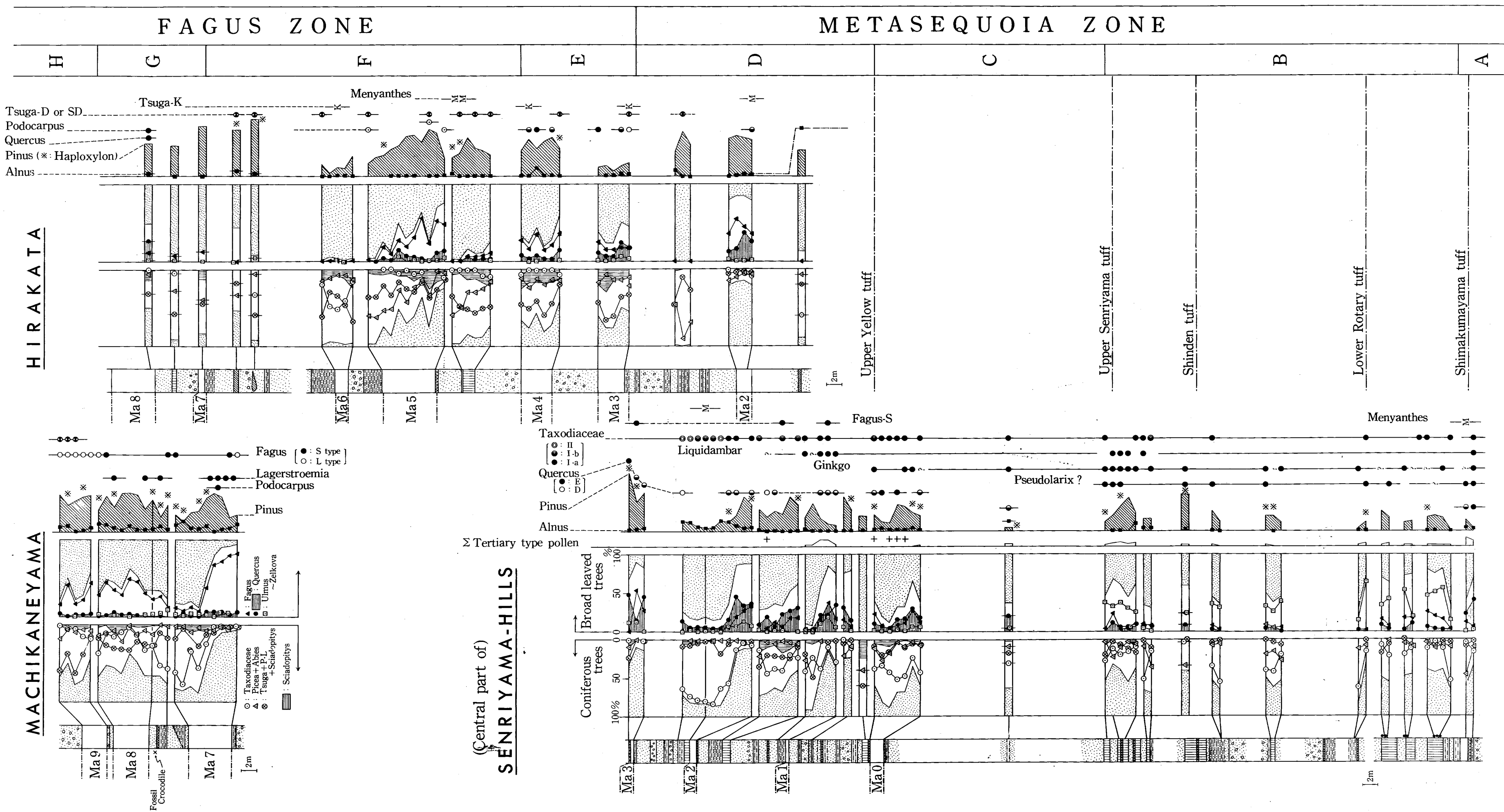


Fig. 2-b. Senriyama Hills and Hirakata Hill,

FUKAKUSA

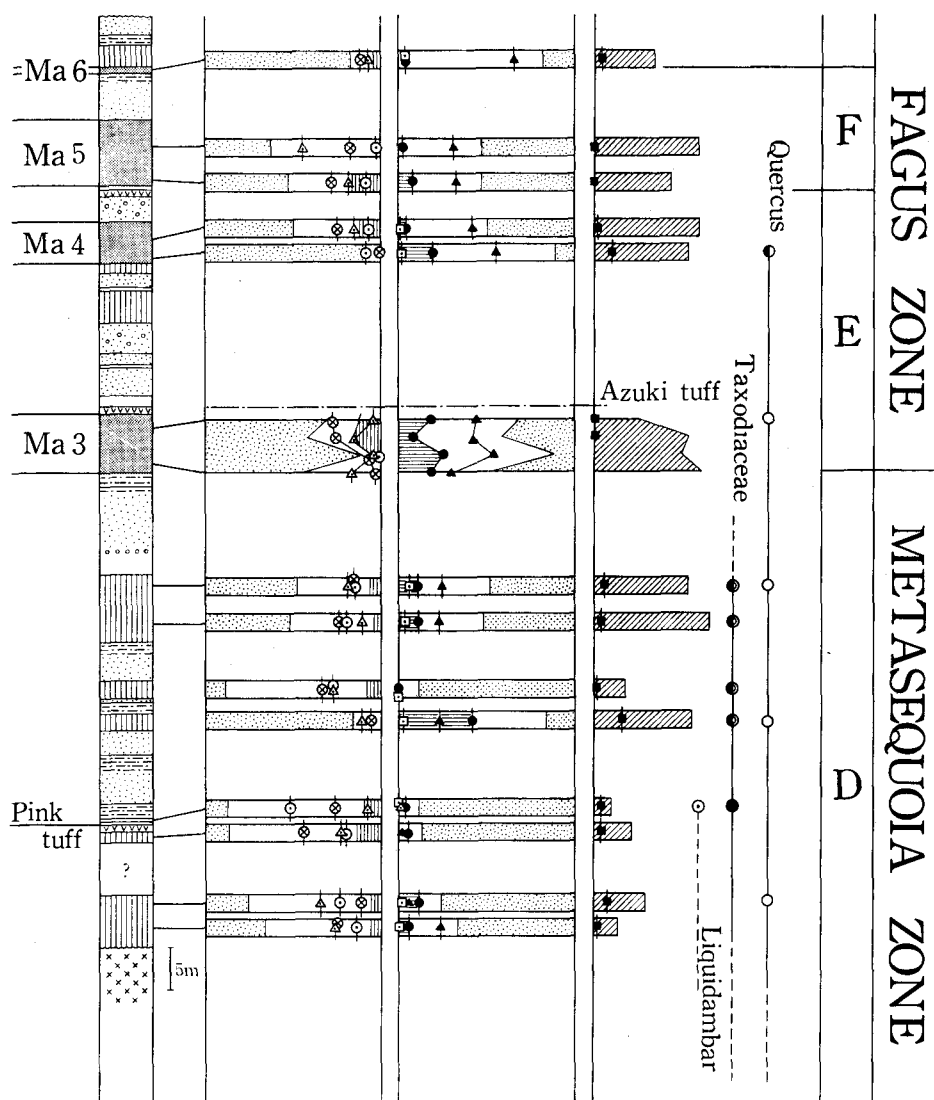


Fig. 2-c. Fukakusa.

Fig. 2. Principal pollen profile of the Osaka group in hilly region.

"Note" Method of counting:

- i) As to the cardinal number of the main tree pollen, the following types such as *Pinus*, *Alnus*, *Salix*, Cupressaceae-Taxaceae type, cf. *Zelkova* and Tertiary type are kept apart from the basic sum.
- ii) The cardinal number of the excluded pollen is the sum of the number of the main tree pollen and the excluded pollen.

P.L.: *Pseudotsuga-Larix* type pollen

subzone. The percentage is low for Taxodiaceae type pollen (occurring in association with *Glyptostrobus* (?)*), and high for *Quercus*-D, D-E and E and *Fagus* S. The *Picea* pollen percentage (A type) increases near the upper limit of A subzone, and the first appearance of *Menyanthes* is characteristic.

B subzone: This subzone ranges stratigraphically from above the upper boundary of A subzone to the horizon above the top of the Senriyama tuff in the Senriyama Hills. With the exception of *Picea* A and Taxodiaceae I-a type pollen, the percentage is remarkably low for the Tertiary type tree pollen; *Keteleeria* is entirely absent. *Pseudolarix* (?) continues to this subzone. *Zelkova-Ulmus* is present consistently and, with a few exceptions, the percentage is low for *Fagus* and *Quercus*,

C subzone: This subzone ranges stratigraphically from above the upper limit of the B subzone to the Upper Yellow tuff in the Senriyama Hills. Comparing with other subzones, this subzone is characterized by the constant presence of Taxodiaceae I-a type pollen, the higher percentage for *Quercus* D-E and -E than for *Fagus*. *Ginkgo* continues to this subzone and *Liquidambar* is sparsely found.

D subzone: This subzone ranges stratigraphically from above the upper boundary of the C subzone to the lower boundary of Ma3 in the Senriyama Hills. Taxodiaceae type pollen changes from I-a to I-b, and finally, it becomes to show a distribution pattern similar to that of II type, at the horizon above the Ma2. It is also characteristic of this subzone that such coniferous tree pollen as *Tsuga*, *Sciadopitys* and *Picea* B (partly including *Picea* A) show high percentage in the fresh-water beds, while the spectrum showing high pollen percentage for *Pinus* is found in the marine beds. Although such difference of the pollen spectrum corresponds with the difference of the sedimentary facies, it is noticeable that, in the non-marine bed (Fr 2-3) below the Ma3 in the Hirakata Hills, the coniferous trees like as *Picea*, *Tsuga* D-S and Haploxylon type *Pinus* show high pollen percentage.

Fagus zone: This zone ranges from above the upper limit of the *Metasequoia* zone to Ma9 in the Machikaneyama. This zone is characterized by high percentage of *Fagus* pollen in marine beds.

E subzone: This subzone ranges stratigraphically from the base of the *Fagus* zone to the upper limit of the Ma4 in the Hirakata Hills. In this subzone, it is characteristic that *Fagus*, *Quercus* E and D-E and *Sciadopitys* are always present consistently in marine beds. In the lower parts of both the Ma3 and the Ma4, *Tsuga* S-D and *Quercus*-D are found.

F subzone: This subzone ranges from above the upper limit of the E subzone to the base of Ma7 at Machikaneyama. The spectra which show high pollen percentage for such coniferous trees as *Picea* B, *Tsuga* D and D-S and Haploxylon

* The pollen has characteristics similar to those of living *Glyptostrobus* pollen (YAMAZAKI and TAKEOKA, 1956).

type *Pinus* are found in fresh-water beds (Fr 4-5 and Fr 6-7), and *Larix* and *Menyanthes* are also present. In marine beds, the pollen percentage becomes lower for *Quercus* and higher for *Fagus*. In Ma5 bed, however, the pollen percentage becomes gradually higher from *Fagus* to *Picea* (including *Picea polita*?) and in Ma6 bed Taxodiaceae II type and *Tsuga* S show a high pollen percentage.

G subzone: This subzone ranges stratigraphically from the base of the Ma7 to the upper limit of Ma8 at Machikaneyama. The subzone is characterized by the fact that pollen percentage becomes higher for *Fagus* S and Taxodiaceae II type (in marine beds), and that in the lower part of the Ma7 and Ma8 such tree pollen as *Podocarpus*, *Lagerstroemia* and *Paliurus* are present. The pollen of *Fagus* increases in size at the base of Ma7 and the upper limit of Ma8. *Menyanthes* is also present at the base of Ma7.

H subzone: This subzone corresponds to Ma9 in Machikaneyama. Compared with G subzone, the pollen of *Fagus* in this subzone increases in size (L type), and the type of *Tsuga* changes from *Tsuga* S to *Tsuga* S-D at the upper part of Ma9.

IV. Correlation between the other area of Osaka Group and the standard pollen succession

Deep drilling core and standard pollen succession

On the basis of pollen analyses, the stratigraphical section of the deep bore hole, OD-1 (Minato-Ku, Osaka City) has been divided into the following zones (TAI, 1966) (Fig. 3).

- 1) The boring core section is divided into lower and upper parts, *i.e.*, *Metasequoia* and *Fagus* zones at the base of Ma3 (at the depth of 413 m).
- 2) The *Metasequoia* zone is subdivided into two parts, *i.e.*, the upper and the lower *Metasequoia* subzones at the upper limit of Ma0. The lower limit of the lower *Metasequoia* subzone corresponds with the boundary (about 700 m in depth) between III-b and IV beds of Ikebe's stratigraphy (OSAKA CITY, 1964).
- 3) At the present time, the upper limit of the *Fagus* zone is indeterminable.

The section ranging from the Ma0 to Ma9 in the OD-1 core can be correlated stratigraphically with the standard pollen succession. The upper *Metasequoia* subzone is correlated to D subzone in the standard pollen succession. The *Fagus* zone in OD-1 core is subdivided into four subzones, *i.e.*, E, F, G and H subzones. The pollen percentage in each zone of OD-1 core is comparable to that of the standard pollen succession. With the exception of the Fr 6-7, the samples for pollen analysis were taken from every horizon of fresh-water beds between marine beds. Accordingly, the result of the analysis is useful in supplementing the missing parts of the pollen diagram in the standard pollen succession. In marine beds, the pattern of the appearance of the tree pollen is rather similar to that of the standard pollen succession.

In Fr 3-4 of E subzone, *Tsuga* S-D occurs in association with *Fagus*, *Quercus* D and Taxodiaceae II type pollen. In Ma6 of F subzone, *Fagus* is dominant in its lower part and *Sciadopitys* in its upper part. Namely, the pollen assemblage differs from that of the standard pollen succession in which Taxodiaceae type II pollen and *Tsuga* are dominant. In the Fr 4-5 and the Fr 5-6, coniferous trees such as *Tsuga* S-D, *Tsuga* D, *Picea* and Haploxylon type *Pinus*, are dominant and *Menyanthes* occurs partly.

The percentage is high for Taxodiaceae II type pollen in Ma8 of G subzone. *Tsuga* S-D occurs in association with the Taxodiaceae type pollen in Fr 7-8 and in the upper part of Ma8.

In the fresh-water bed overlying Ma8 of H subzone, *Picea* becomes predominant in association with *Tsuga* S-D. In the lower part of Ma9, *Fagus* L is predominant and the pollen assemblage is similar to that of the standard pollen succession. In the middle and the upper parts of Ma9, however, the pollen percentage is high for *Sciadopitys* and *Tsuga* (S type, S-D type and K type) and low for broad-leaved trees.

A horizon near the boundary (about 700 m in depth) between III-b and IV beds yields high percentage of *Picea* and *Pinus*. Judging from the pattern of the distribution of grain size, *Picea* of this horizon can be identified as an intermediate type between the A and the B types (Fig. 8-b). The spectrum corresponding with this horizon is absent in the standard pollen succession.

The frequency distribution of the pollen in the deposits below the depth of 700 m (IV bed)

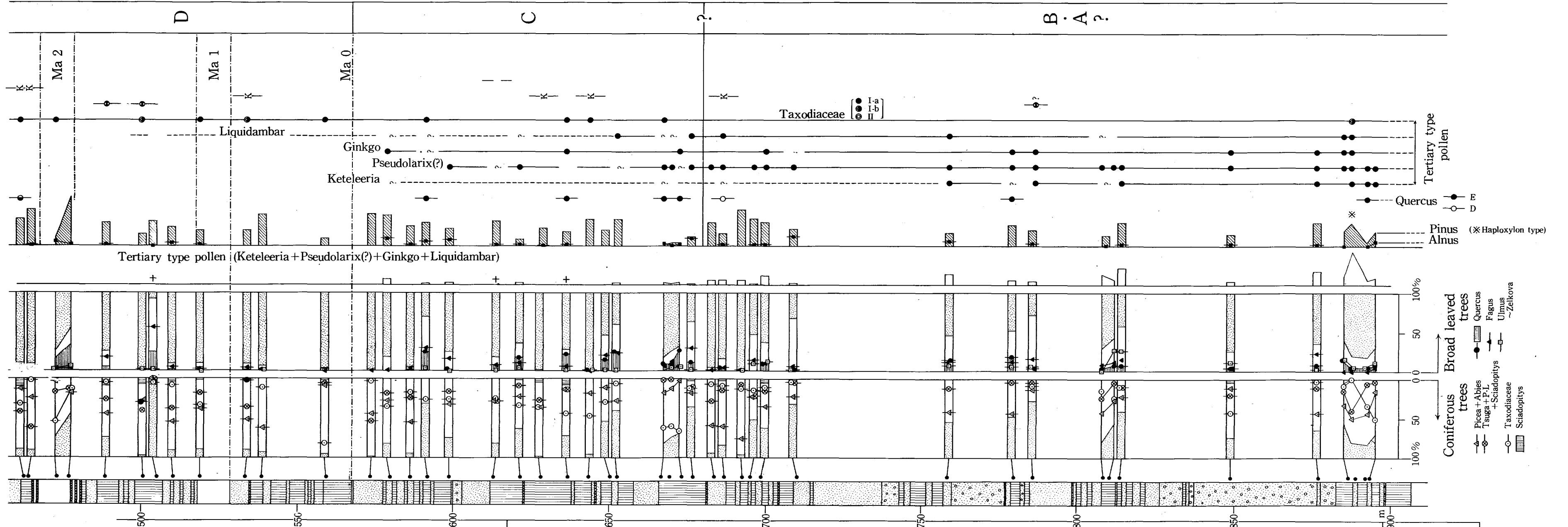
Tertiary type pollen, such as *Keteleeria*, *Pseudolarix* (?), *Ginkgo* and *Liquidambar*, are sparsely found. In general, the percentage of them rises slightly toward the lower part. Of the Tertiary type pollen, *Pseudolarix* (?) shows comparatively high percentage and *Liquidambar* occurs only near the lower boundary. Coniferous trees, such as Taxodiaceae type pollen and *Picea*, show higher pollen percentage than that of B subzone of the standard pollen succession. *Quercus* (including E type) and *Fagus* are present consistently. As a whole, however, the pollen assemblage has many similarities to that of the B subzone of the standard pollen succession.

Keteleeria is comparatively consistent in the deposits below the depth of 880 m, and Taxodiaceae type pollen found in the lower limit has the distribution pattern of I-b type. In general, the tree pollen assemblage are similar to those of A subzone of the standard pollen succession.

Pollen succession in Fukakusa and Tannowa

(1) Fukakusa (Fushimi-ku Kyoto City), (TAI, 1963): It is known that the Osaka group in this district ranges from the horizon of the fresh-water clay bed lying 5-6 m below the Pink tuff to the horizon of Ma6.

METASEQUOIA ZONE



FAGUS ZONE

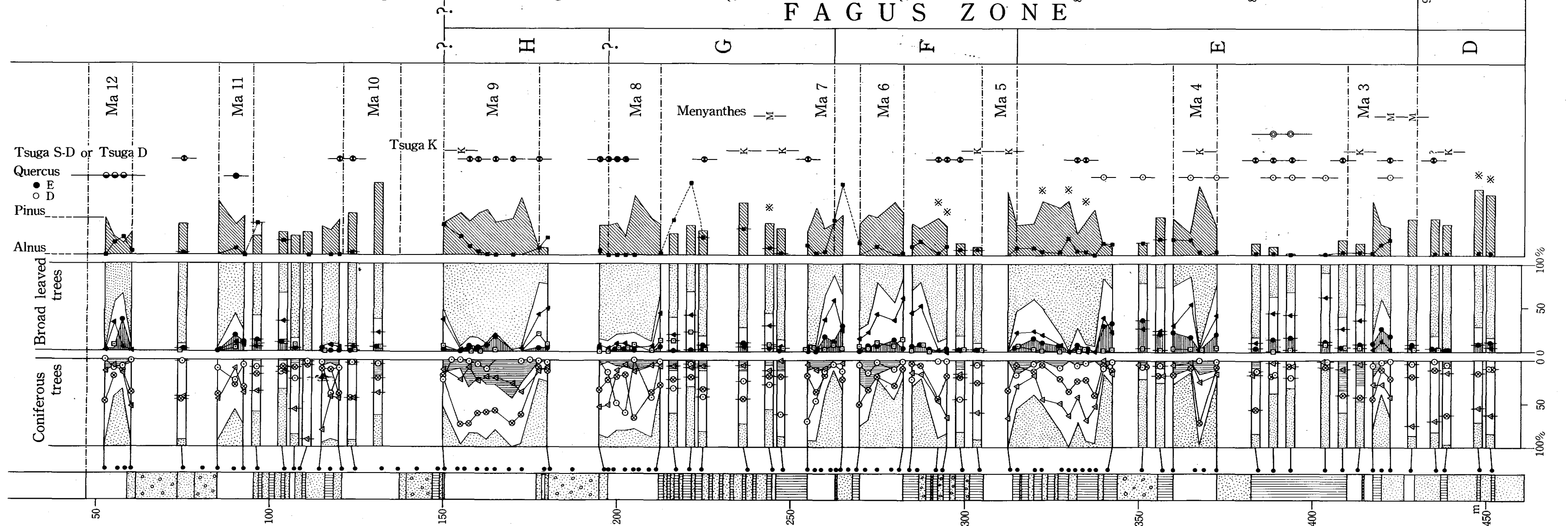


Fig. 3. Principal pollen profile of the deep broing core, (OD-1) in Osaka City.

The *Metasequoia* zone in Fukakusa, with the exception of its lower limit, can be correlated stratigraphically and palynologically with the D subzone of the standard pollen succession. Namely, Taxodiaceae type pollen is made of the I-b type, and the Tertiary elements have already vanished with the exception of Taxodiaceae type pollen and *Picea* A, and the broad leaved trees, such as *Fagus* and *Quercus*, are found rather frequently.

In the lowermost part of this zone, the Tertiary type pollen are more abundant than in the overlying part. The pollen spectrum of the lowermost part indicates that Taxodiaceae type pollen is distributed in a pattern similar to that of I-a type, and *Liquidambar* is also present in this part. The pollen composition indicates that the assemblage is very similar to that of D subzone of the standard pollen succession.

The *Fagus* zone is characterized by the fact that the pollen percentage for *Fagus* is high in four marine clay beds. The frequency distribution of pollen, such as that of *Fagus*, *Quercus* and *Picea*, in these four marine clay beds corresponds to the pollen assemblage of each subzone of the standard pollen succession. In the Ma6, the percentage is low for Taxodiaceae type II and *Tsuga*, while it is high for *Fagus*.

(2) Tannowa (Sennan-Gun, Osaka Prefecture) (TAI and UENO, 1965): The Osaka group found in Tannowa is regarded to be one of the lowermost member of the group, but it has not been ascertained whether it corresponds with the group in the Tsuchimaru-Oike.

In the pollen assemblage, *Keteleeria*, *Pseudolarix* (?) and *Liquidambar* are present. The pollen percentage is low for Taxodiaceae type pollen and is higher for *Quercus* D and D-E than for *Fagus*. The pollen assemblage has characteristics similar to those of the A subzone in the standard pollen succession and of the lowermost part of OD-1 cores.

V. Pollen flora from the beds bearing the plant remains

Pollen from the beds which yield the cold type plant remains

It has been known that the plant remains suggesting the cold climate were yielded from the Osaka group in Gokenya, Manzidani, Komyo-ike and Toyonaka. The horizons of those plant remains are directly below the Ma3 (Gokenya, ITIHARA, 1960, 1961) and also just below Ma7 (Manzidani and Komyo-ike, ITIHARA *et al.*, 1965). As for the remains from Toyonaka, the stratigraphical position and the details have not yet been clarified, but according to S. ISHIDA (personal information), the horizon is regarded to be Ma8 or Ma9.

The sampling horizons and percentage of main tree pollen of those districts are given in Fig. 4, and the percentage of the other pollen and spore is also given in Table 2.

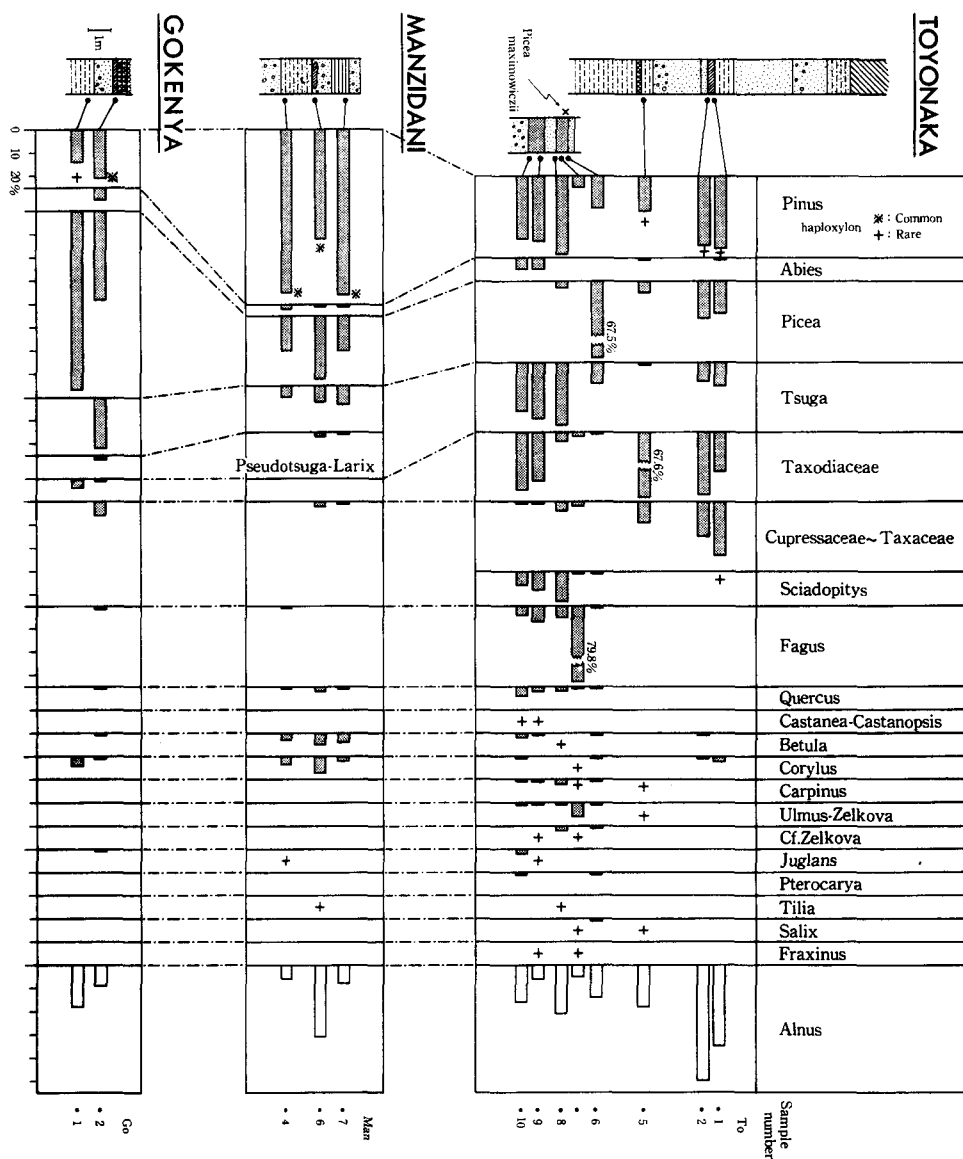


Fig. 4. Pollen diagram of beds containing the cold type plant remains.

Table 2. Percentages of pollen and spores which are excluded from the pollen diagrams of Fig. 4.

Species	Localities & Sample No.		Gokenya			Manzidani			Toyonaka							
	Go-1	Go-2	Go-1	Go-2		Man-4	-6	-7	To-10	-9	-8	-7	-6	-5	-2	-1
Ilex	2.0					0.3	0.4		0.6	0.3	1.0		0.3	2.1	2.9	1.1
Symplocos											0.3	0.3		0.5		
Lonicera											1.3					0.2
Elaeagnus																0.2
Ericaceae						1.2	0.8				1.3					
Rhus									0.3							
Ligustrum?	0.4									0.5			1.4	0.8	0.4	0.2
Buxus											0.3					
Compositae (w. long spin)	0.4		0.4	0.3	1.9					2.3	0.3		1.4	2.9	2.0	1.3
Taraxacum type													0.3	0.3		0.1
Artemisia	0.4				1.4											
Caryophyllaceae									3.6	1.6	1.8	0.3				1.6
Umbelliferae	0.4		0.4						0.3			1.4				
Patrinia	0.4															
Chenopodium	0.4															
Lilium														0.3		
Gramineae	27.5	6.4	4.8	2.5	5.9	1.1	2.3	6.2	7.2	6.0	6.0	4.3	4.0			
Cyperaceae	6.1	3.0	0.4	3.3		0.3		1.0	0.3						0.2	0.6
Persicarya					0.4								0.3	0.3	0.5	0.2
Nuphar																
Myriophyllum?					0.3				0.3							
Menyanthes	1.9				0.3	0.4					0.3	0.3				
3 colpate	4.8	1.7	9.8	1.7					6.0	2.0	1.6	0.3	1.3	0.3	0.4	3.3
3 colpate	1.0	4.0	1.1	1.2					4.7	4.0	3.9	4.3	0.3	0.5	0.5	0.7
2-5 porate	1.0			1.7	1.0											
Forate	1.0								0.8							
Inaperturate-Monoporate	9.5	6.6	5.5	9.4	7.5				3.3	4.3	3.6	4.0	8.3	4.2	5.2	10.5
Osmunda					1.1	0.9			0.8	0.6						
Lycopodium															0.1	0.1
Selaginella?					0.2											
Trilete indet		0.3	1.3	1.3	3.0				0.6	0.8	0.9	1.1	0.8	17.4	5.5	
Monolet indet	83.5	0.6	8.0	5.0	8.3	1.1	1.6	2.1	2.2	27.1	1.1	1.7	4.5			
Sphagnum	0.2	3.2	2.7	2.2	0.9										7.5	2.0
Total number of pollen & spores	646	316	299	462	339				371	313	398	361	437	392	770	1001

(1) Gokenya (Tondabayashi City, Osaka Prefecture): Two samples have been examined. From the upper lignite layer, the occurrence of such plant remains as *Menyanthes trifoliata*, *Alnus* and *Picea* has been reported.

The pollen spectra show that the pollen percentage is low for broad leaved trees and high for coniferous trees and herbs. Of the coniferous trees, *Picea* shows the highest pollen percentage and *Pinus* (including Haploxylon type) shows comparatively low pollen percentage, and *Sciadopitys* is absent. Of the broad leaved trees, *Alnus* shows comparatively high percentage, and *Corylus*, *Betula*, *Quercus*, *Fagus*, and *Juglans* are sparsely found. Of the herbs, spore and Gramineae show high percentage. In the samples from the lower horizon, spore (Monolete type, of which perin dropped out) shows the highest percentage. The pollen assemblage is simple and the kinds of tree pollen are limited. A small amount of Taxodiaceae type pollen is present.

In the sample from the upper horizon (lignite layer), *Tsuga* S type (see Fig. 8-a), *Abies*, Cupressaceae-Taxaceae type pollen and *Pseudotsuga* show relatively high pollen percentage and broad leaved trees and herbs increase in number of kinds. *Sphagnum* spore shows higher percentage in the upper horizon than in the lower horizon, and *Menyanthes* is also present.

(2) Manzidani (Koyoen, Nishinomiya City, Hyogo Prefecture): Plant remains found in the deposits and their corresponding fossil pollen are given in Table 3.

Pinus (including Haploxylon type) shows the highest pollen percentage and the percentage for *Picea* and *Tsuga* is subordinate to the former. With the exception of the samples from the lower horizon, *Tsuga* has the distribution pattern of the D type (see Fig. 8-a). *Abies* is present in low percentage throughout the samples. Of the broad leaved trees, *Alnus*, *Betula* and *Corylus* show relatively high pollen percentages, and *Quercus* is also present in all the samples, though the pollen percentage is low.

Of the herbs, Gramineae and *Sphagnum* are present in all the samples, and *Menyanthes* is also present in several samples.

(3) Komyo-ike (Izumi City, Osaka Prefecture): From the lower lignite layer, *Menyanthes* was reported (ITIHARA *et al.*, 1965). As far as two samples have been examined, Taxodiaceae type pollen shows high pollen percentage, and with the exception of *Alnus*, the broad leaved trees show low pollen percentage. Of the herbs, Gramineae and monolete type spores are frequent. The distribution pattern of *Tsuga* is D type or D-E type (see Fig. 8-a), and *Menyanthes* is also present in the two samples.

(4) Toyonaka (Toyonaka City, Osaka Prefecture): From the uppermost part of the upper marine clay bed in Toyonaka, a large number of cones of *Picea maximowiczii* were found. The pollen diagram shows an irregular frequency

Table 3. Plant remains and pollen yielded from the Manzidani Conifer bed.

Mega plant remains			Pollen	
Species	Miki	Kokawa	Amount	Pollen type
<i>Abies firma</i>	+	+	R	Abies
<i>Abies homolepis</i>	+			
<i>Abies veitchii</i>		+		
<i>Picea jezoensis</i> var. <i>hondoensis</i>	+		A	Picea (B)
<i>Picea bicolor</i>	+	+		
<i>Picea maximowiczii</i>	+	+		
<i>Pinus koraiensis</i>	+	+	A	<i>Pinus haploxylon</i>
<i>Chamaecyparis psifera</i>	+	+	R	Cypressaceae-Taxaceae
<i>Thuja protojaponica</i>	+	+	R	Cypressaceae-Taxaceae
<i>Larix gmelini</i>	+	+	R	<i>Pseudotsuga-Larix</i> (include <i>Larix</i> type)
<i>Tsuga oblonga</i>	+		?	<i>Tsuga</i> S <i>Tsuga</i> D
<i>Tsuga sieboldii</i>		+	C	
<i>Tsuga diversifolia</i>			C	
<i>Betula platyphylla</i>	+	+	C	<i>Betula</i>
<i>Prunus salicina</i>	+	+	-	<i>Prunus</i>
<i>Prunus maximowiczii</i>	+			
<i>Acer miyabei</i>	+		-	<i>Acer</i>
<i>Alnus tinctoria</i>		+	A	<i>Alnus</i>
<i>Potamogeton pectinatus</i>		+	-	<i>Potamogeton</i>
<i>Nuphar akasiensis</i>		+	-	<i>Nuphar</i>
<i>Ceratophyllum demersum</i> <i>Ceratophyllum submersum</i>		+	?	?
<i>Menyanthes trifoliata</i>			R	<i>Menyanthes</i>
<i>Corylus heterophylla</i>	+	+	C	<i>Corylus</i>

distribution and the kind of pollen which shows high pollen percentage is different from sample to sample. The tree pollen of high percentage changes in the following sequence in ascending order.

1. Taxodiaceae type, *Tsuga*→2. *Fagus* L→3. *Picea*→4. Taxodiaceae type→5. Taxodiaceae type, Cupressaceae-Taxaceae type, *Picea*.

Sciadopitys ranges up to Horizon 1 cited above, and the broad leaved trees show

Table 4. Percentages of pollen and spores which are excluded from the pollen diagrams of

Pollen & Spore types	Locality Sample number	Komyo-ike (Ko.)									
		10	9	7	6	5	4L	4U	3	2	1
Ericaceae								0.4			
Styrax										0.3	
Ilex		0.6	1.5		0.4	2.9	2.1	1.2	1.8		
Symplocos					0.4	0.9	0.6	0.4			0.6
Lonicera					0.8	3.5	0.3	0.8	0.4		
Elaeagnus				0.3							
Rhus		0.3									
Sapindus											
Cornus											0.3
Ligustrum?			0.5	0.3	1.3	1.4	0.3	0.4	0.4		0.6
Ludwigia											
Vitis					0.1						
Compositae (w. long sp.)		0.9	1.0		7.4	2.0	1.2	0.8		0.3	
Compositae (Taraxacum type)		0.3		0.3	0.3			0.8		0.3	1.1
Artemisia		0.3	0.5						0.4		
Scabiosa					0.1						
Caryophyllaceae			0.2			0.6		0.4			
Umbelliferae		0.7	0.5	0.3							
Chenopodium											
Kochia?				0.3							
Lilium											
Gramineae		6.8	4.1	4.8	38.3	3.7	3.1	2.0	2.2	2.6	3.2
Cyperaceae		4.7	1.9	0.3		1.7	1.2		1.4	1.6	2.6
Persicaria		1.0	0.3		0.1	0.6	0.6	0.8	0.7	0.6	
Typha-Sparganium type											
Nelumbo											
Trapa											
Nuphar			1.0								
Myriophyllum?				0.3							
Menyanthes		1.0	4.4			0.3					
3 colpate		1.3	1.5	1.8	3.7	0.9	1.2		0.7	2.3	2.3
3 colpate		1.3	1.7	2.7	0.5	0.6	0.3	2.4	2.5	0.6	1.7
2-5 porate		0.1							0.4	0.3	0.3
Forate					0.4		0.3			0.3	0.4
Inaperturate-Monoporate		19.9	19.7	9.7	15.1	7.1	1.8	3.6	3.6	7.1	0.7
Osmunda		0.3	1.1	0.5	1.7			0.4	0.3		
Lycopodium							0.3				
Trilete		2.7	1.6	6.4	2.3		0.6	0.8	1.7	1.8	1.3
Monopolete		11.1	4.7	9.0	5.5	2.3	2.1	1.2	2.8	2.8	6.0
Sphagnum			0.7								
Total number of pollen & spores		790	448	394	848	355	337	259	291	326	372

lower ← ※ → upper

※Kasuri tuff horizon

Fig. 5.

Imakuma							Hirakata				Fukui		Mitsuike
1	2	3	4	5	6	7	0	2	3	5	2	6	1
			0.3								0.7		
	0.4	3.9	1.7		1.3	2.7		0.8		0.4			0.2
		0.6			0.3	0.3			0.3		0.7		
									0.7		3.0	0.4	
			0.3				0.3		0.3				
	0.4	0.3			0.3	0.3			0.3			0.4	
				0.4									
			0.3		1.3	0.5	0.3	3.0		0.2	1.5	0.8	1.0
		0.3				0.3				0.2			
		0.3								0.2			0.2
		0.3				0.3				0.2			0.2
		0.3	0.3							0.2			
						0.3			0.3				
						0.3		0.4					
0.9		4.5	1.7	1.8	3.4	2.2	1.6	6.0	6.6	2.7	3.7	3.8	16.7
			1.0	1.4	0.9	4.9	0.8	0.8	1.3	0.8	1.5	0.3	3.1
		0.3					0.5	0.4		0.6			0.6
					0.6	0.3		0.8					
									0.3				
0.3													
		5.3	3.7	3.2	0.6	1.4	1.0		0.3	25.9	1.5	2.3	1.3
		1.1	1.3			2.7	0.5		1.0	18.3	0.7	0.6	0.6
					0.3	0.5	0.3	0.4	0.3	0.6			
14.8		5.6	3.7	4.2	2.2	15.6	3.6	1.1	5.6	3.9	15.7	6.1	4.2
				0.3		0.3		0.7	0.7	0.4		0.7	0.6
										0.4			
0.4		0.3	0.3	0.3		0.8	1.1	1.1	0.3	0.8	3.0	1.1	6.3
0.4	1.5	0.6	0.7	0.7	5.3	4.2	1.6	0.4	2.5	4.3	46.8	0.6	16.8
266	284	361	303	284	339	385	396	272	313	517	229	285	628
		※						※			※		※

higher pollen percentage in the lower horizon. *Tsuga* assumed to be the S type in the lower horizon changes to D or D-S type in the upper horizon (see Fig. 8-a). *Fagus* shows L type distribution (see Fig. 8-c).

In almost all of the samples, especially in the samples from the upper horizon, *Alnus* shows high pollen percentage. *Sphagnum* is also frequent in the samples from the upper horizon. *Menyanthes* is present in Horizon 4.

Pollen flora from Syzygium bed and Kasuri tuff horizon

It has been known that the lower part of Ma8 yielded warmth-loving plant remains like as *Syzygium*, *Quercus* (*Cyclobalanopsis*), etc. (MIKI *et al.*, 1957; KOKAWA, 1959; TAKAYA and ITIHARA, 1961; ITIHARA *et al.*, 1965). In order to examine the pollen assemblages above and below that horizon, the samples were taken from the following localities.

- Komyo-ike (Izumi City, Osaka Prefecture)
- Imakuma (Sayama-Cho, Minami-Kawachi-Gun, Osaka Prefecture)
- Hirakata (Bussharito, Hirakata City, Osaka Prefecture)
- Fukui (Ibaragi City, Osaka Prefecture)
- Mitsuike (Kumanoda, Imakuma City, Osaka Prefecture)
- Machikaneyama (Toyonaka City, Osaka Prefecture)

Sampling horizons and the frequency distributions of the main tree pollen are given in Fig. 5, and the frequency distributions of other pollen and spore are given in Table 4 except for Machikaneyama and Hirakata (Shinkori formation; TAI, 1963) of which distribution is shown in Fig. 2-b.

The pollen percentages of *Pinus*, *Alnus*, shrubs and herbs differs with places, and then it is difficult to grasp general tendency. As for the tree pollen, however, following characteristics can be shown. Haploxylon type *Pinus* shows a high pollen percentage in most of the samples, and the spectrum in which the percentage is high for Taxodiaceae type pollen is frequent. The percentage of Taxodiaceae type pollen rises at the horizon below the Kasuri tuff at Komyo-ike, while in the other districts it rises at the horizon immediately above the Kasuri tuff. But it is out of doubt that the regional rise of the Taxodiaceae type pollen percentage is observed above the Kasuri tuff horizon.

As for other tree pollen, the percentage is high for *Fagus* in the upper part of the Ma7 in Hirakata and for *Zelkova-Ulmus* in the upper part of the Kasuri tuff at Imakuma. The spectrum in which *Quercus* E shows high pollen percentage is present only in the base of the Ma8 in Hirakata (Compare Fig. 5 with Fig. 2-b). *Tsuga*, as far as the writer examined, is of *Tsuga* S type. *Fagus* of the larger type is found in the uppermost part of Ma7 at Hirakata and in the horizon above the Kasuri tuff in Fukui, and *Fagus* of smaller type is found in the horizon immediately above the Kasuri tuff in Hirakata (see Fig. 8-c). Accordingly, it is safe to say,

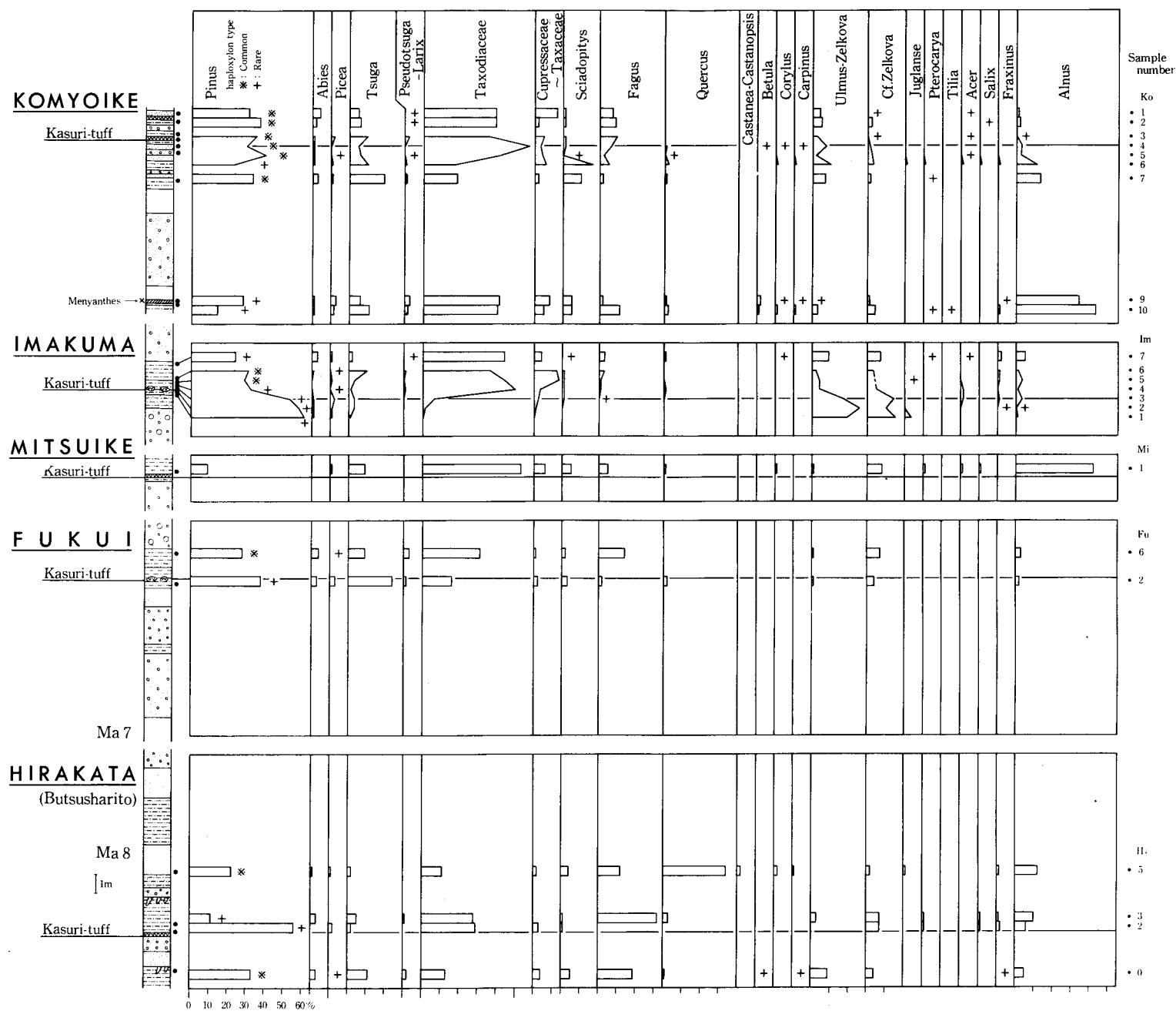


Fig. 5. Pollen diagram of the Kasuri-tuff horizon.

that pollen spectra which indicate definite warm climate have not been found in and below the Kasuri tuff horizon.

VI. Problems on the identification of pollen

Size frequency distribution

As it is difficult or impossible through palynology alone to provide a good picture of local vegetation, palynological studies usually require the species identification supported by some evidences of mega-fossils. Due to the rather broad distribution of most genera, a direct paleoclimatic interpretation of many spectra is limited.

Recently new techniques using size frequency distribution of pollen grains have been developed (NAKAMURA; 1957; 1968; TSUKADA, 1966). In spite of the controversy (SATO; 1965; 1967), the writer adopted one of these techniques, and the data were checked by comparison with abundant informations on mega-fossils. The results obtained from these two sources so far agreed well with each other, and the size frequency distribution technique used by the writer seems to be valid at least in the case of the Osaka group.

Some remarks on the preparation of the size frequency distribution curve and its implication for the results will be introduced as following.

Consideration on the size frequency distribution of fossil pollen grain

Preparation of the frequency curve: Taxodiaceae (probably *Cryptomeria*), *Tsuga* and *Fagus* which were obtained from the samples of the strata ranging from the Ma7 and Ma9 were examined by means of Tai's method (TAI, 1969): That is, a hundred pollen were counted and measured for each pollen type.

Variance of population: Mean value of grain size for Taxodiaceas was calculated for each sample, and termed M_{c1} , M_{c2} ,, M_{cn} . Next Thompson's method applied to determine whether the mean values belong to a parent population or not. Two mean values out of thirtytwo were rejected with the 5% significance level. This shows that even with controlled treatment, swelling or shrinking occurred in different degrees in different cases during the process. After rejecting the two samples, the mean values were found to distribute from $30.49 \pm 0.58 \mu$ to $34.71 \pm 0.84 \mu$ having a variance of about 10% of the grand average (where the grand average is: $\overline{M_c} = 32.60 \pm 0.25$, $\overline{M_c} = \sum M_{ci}/n$) (TAI, 1969).

General tendency of grain size change: Mean values of grain size for *Fagus*, *Tsuga*, and Taxodiaceae were calculated in each horizon, with M_{f1} , M_{f2} and M_{c1} in horizon 1, M_{f2} , M_{t2} and M_{c2} in horizon 2 and so on. Then the correlation coefficients (r) among the three plants were calculated. The result was that the coefficient (r) ranges from 0.55 to 0.75 at the significant level of 5% as shown in Fig. 6. This implies that there exists parallel tendency in change of

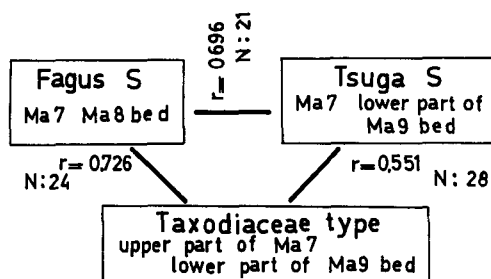


Fig. 6. Correlation in grain size of *Fagus*, *Tsuga* and *Taxodiaceae* type pollen.
r: Correlation co-efficient, N: Sample number.

grain size among the three plants.

Stratigraphical fluctuation of corrective mean value of grain size for *Fagus*, and *Tsuga*: Corrective mean values of size for *Fagus* and *Tsuga* were obtained by the following formula:

$$P_{fi} = 32.6 \times \frac{M_{fi}}{M_{ci}}, \quad P_{ti} = 32.6 \times \frac{M_{ti}}{M_{ci}}$$

P_{fi} , P_{ti} : corrective mean values of size for *Fagus* and *Tsuga* in each sample.

The stratigraphical fluctuation of the corrective mean value is shown in Fig. 7. Those values for *Fagus* obtained from Ma9 bed, converge around 40μ , whereas those from the lower horizons gather around 35 to 36μ . As to the grain size of *Tsuga* the corrective mean values are about 70μ in the horizons lower than the middle part Ma9, and become larger in the upper zones. This distribution tendency is not much different even when the rejected samples are incorporated.

In order to improve the grain size analyses, FAEGRI and IVERSEN (1964) proposed a method in which standardized grain size can be obtained. NAKAMURA (1968) has applied a similar technique in his studies of the Pleistocene *Betula*. The writer believes that these methods must be useful for the future studies of the pollen of the Osaka group.

Identification of pollen

Tsuga pollen (Fig. 8-a): Plant remains of *Tsuga diversifolia*. *T. sieboldii*, *T. rotundata*, *T. oblonga* and *T. longibracteata* are reported from the Osaka group. Of these *Tsuga sieboldii* ranges from the early stage of the deposition of the Osaka group up to the present, and *Tsuga diversifolia* which is still existing shows its first appearance just above Ma8 (KINKI GROUP, 1969). The rest are all extinct (see Fig. 9).

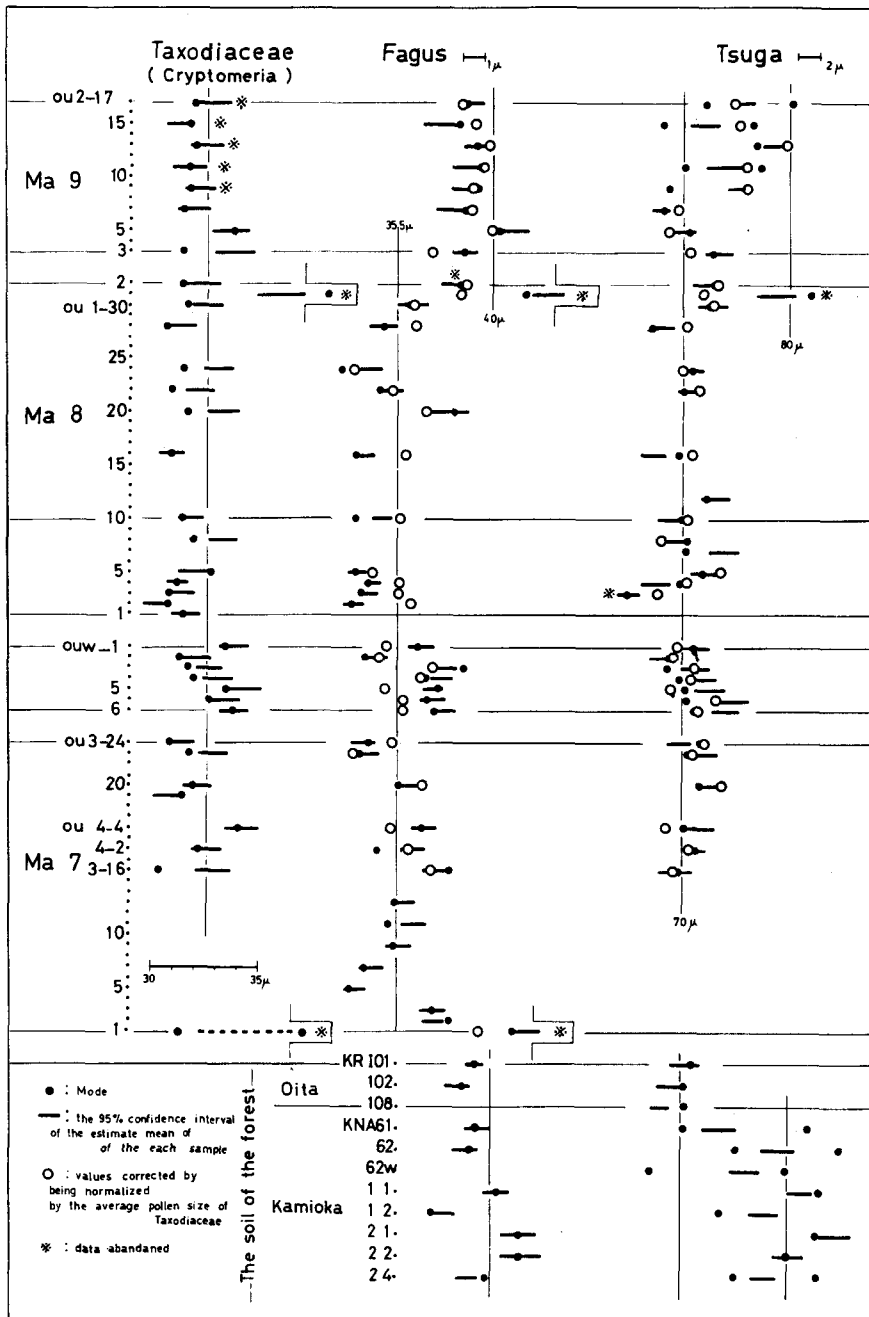
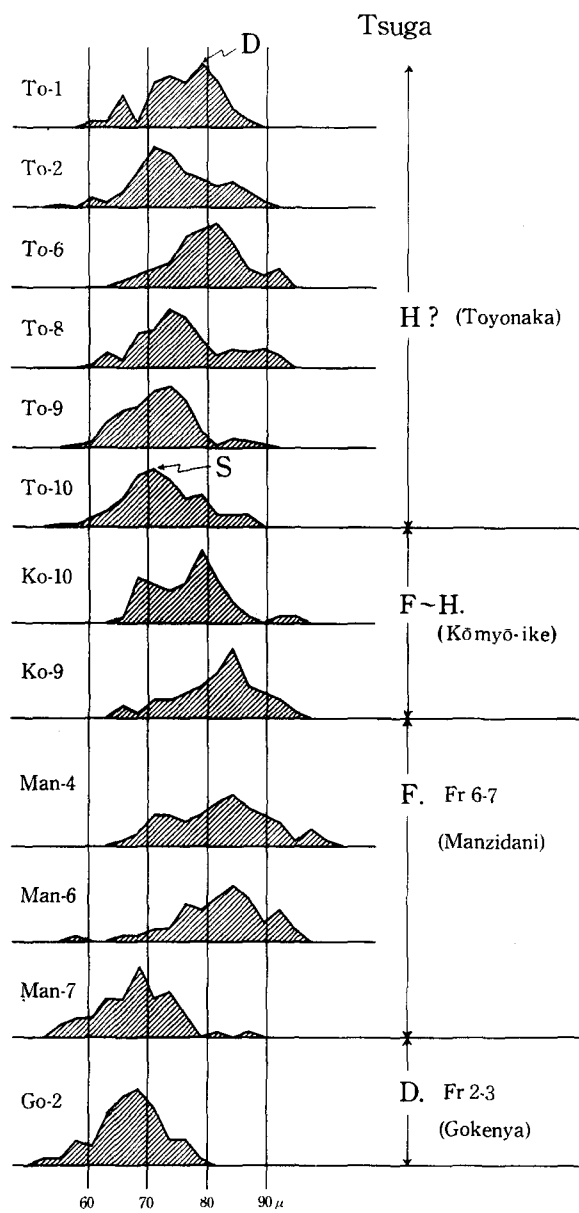
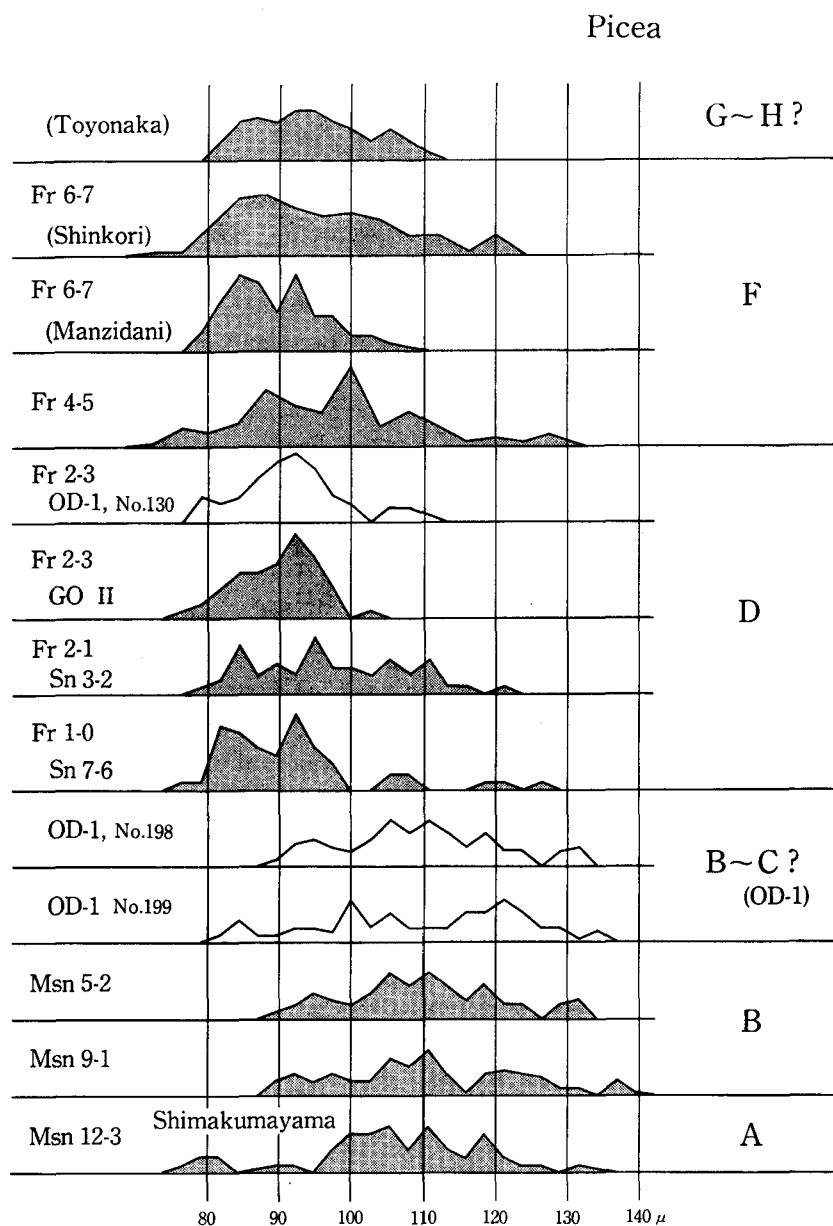


Fig. 7. Stratigraphical distribution of the grain size of pollen. (after TAI, 1969)

Fig. 8-a. *Tsuga*,

Fig. 8-b. *Picea*,

Size frequency distribution demonstrates that the *Tsuga* S-type pollen is common throughout all the subzones from A to H subzones, whereas the S-D type and D-type pollen appear above the base of D subzone. Judging from the pollen and plant remains association, the *Tsuga* S-type is determined to be *Tsuga sieboldii*. The picture of the *Tsuga* S-D type and *Tsuga* D-type pollen is still vague, but again from a comparison with the succession of plant remains, the writer supposes that the S-D type and the D-type pollen represent the predominating *Tsuga sieboldii* and *Tsuga diversifolia* floral assemblages respectively. K-type *Tsuga* pollen may correspond with *Tsuga oblonga*.

Picea pollen (Fig. 8-b): The remains of extinct *Picea koribai* have been reported from various strata ranging from the lowest part of the Osaka group up to the horizon near the Ma1 (NIREI, 1968). Judging from the stratigraphical position, A-type pollen of *Picea* is most probably to correspond to this extinct species. In the Osaka group the species which appears first among the existing *Picea* in Japan is *Picea maximowiczii*, which is found at the very bottom of the Osaka group (KINKI GROUP, 1969). Otherwise, *Picea polita* and *Picea bicolor* are found in rather higher horizons as in the lower part of the Osaka group (KINKI GROUP, 1969; KOKAWA, 1959, 1961) (see Fig. 9).

The modern *Picea* species are all smaller in pollen grain size than the *Picea* of A-type (see Table 1) and can be grouped into *Picea* of B-type. According to UENO (1958), only *Picea polita* can be distinguished from the rest of B-type *Picea* by its morphological character.

In Fig. 8-b, the pollen size distribution demonstrates that while D subzone and the horizons above it are characterized by *Picea* pollen of smaller grain size, B subzone is characterized by *Picea* A-type pollen of which grain size is larger than 100 μ . The first appearance of *Picea polita* (?) is shown in D subzone, which is known also from plant remains. As samples of the OD-1 drilling core yield both *Picea* A and B-types pollen at a depth of about 700 m (Fig. 8-b), the writer assumes that this particular horizon may correspond with the horizon ranging from the B to D subzones of the standard column.

Taxodiaceae type pollen: The pollen of *Metasequoia*, *Glyptostrobus*, *Sequoia* and *Cryptomeria* are included in this type. Among them, only the pollen of *Metasequoia* is smaller than 30 μ in diameter. The rest apparently have larger diameter. It is difficult or impossible to discriminate *Glyptostrobus*, *Sequoia* and *Cryptomeria* from one another in either shape or size. The following evidences have become to be known from the association of mega-plant remains in the Osaka group (see Fig. 9).

- a) In the lowermost part of the Osaka group, *Metasequoia* coexists with *Glyptostrobus* and *Sequoia*.
- b) *Metasequoia* coexists with *Cryptomeria* in the lower part of the Osaka group.

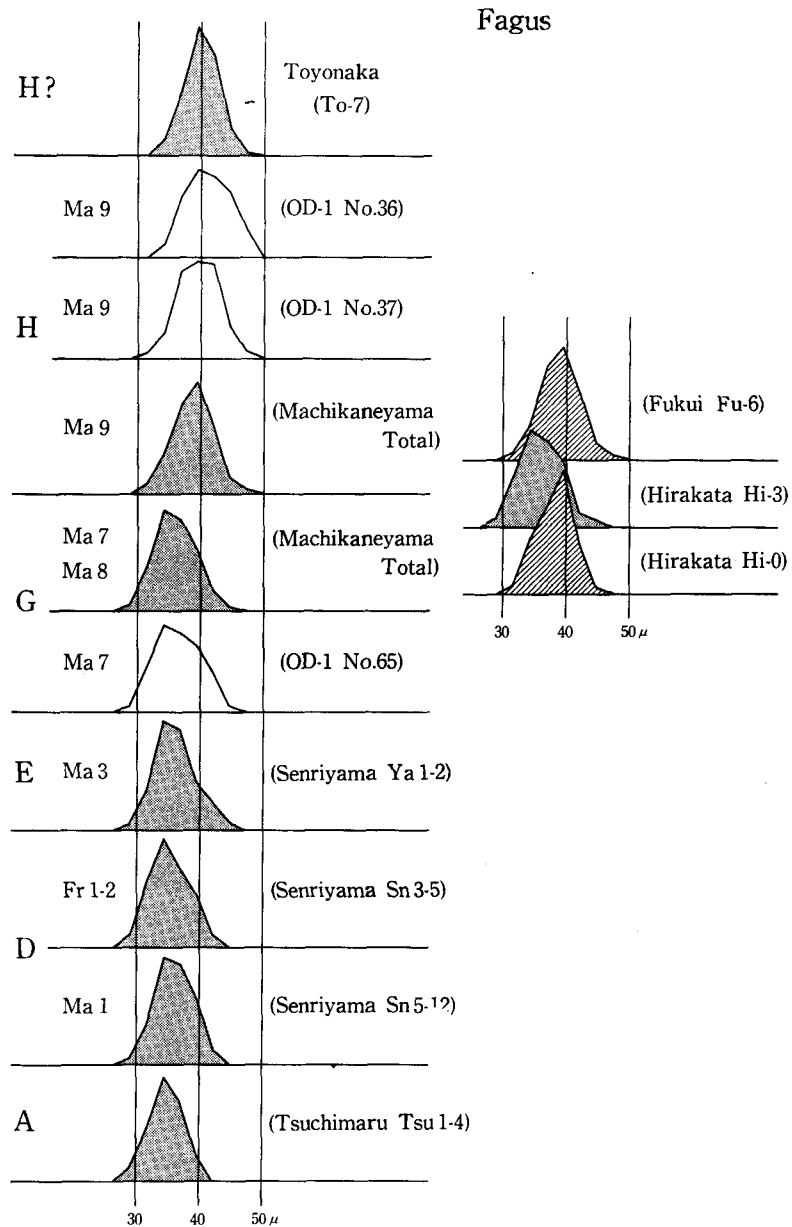

Fig. 8-c. *Fagus*.

Fig. 8. Distribution of the size of fossil pollen.

[illegible]

- c) *Metasequoia* is limited below the bottom of Ma2.
- d) *Cryptomeria* is seen continuously throughout the upper part of the Osaka group.

Taking the above mentioned evidences into consideration, it may be possible to interpret the palynological data concerning Taxodiaceae as the following:

- a) Taxodiaceae type pollen associated with *Metasequoia*, *Glyptostrobus* and *Sequoia* at the lowermost part of the OD-1 core show I-b type floral assemblage.
- b) Taxodiaceae type pollen associated with dominant *Metasequoia* in B to D subzones show I-a type floral assemblage.
- c) Taxodiaceae type pollen characterized by the co-existence of *Metasequoia* and *Cryptomeria* in D subzone shows I-b type assemblage.
- d) Taxodiaceae type pollen associated with dominant *Cryptomeria* in E to H subzones shows II type assemblage.

Fagus pollen: Plant remains of *Fagus ferruginea*, *F. hayatae*, *F. microcarpa* and *F. japonica* are reported from the lowermost part of the Osaka group (MIKI; 1948, 1955; MIKI *et al.*, 1962; KINKI GROUP, 1969). The upper part of the Osaka group yields various species of unidentified *Fagus* besides *F. hayatae* and *F. microcarpa* (FUKAKUSA RESEARCH GROUP, 1962; HUZITA, 1954; ITIHARA, 1960; ITIHARA, *et al.*, 1955; KINKI GROUP, 1969; MIKI *et al.*, 1962) (Fig. 9). Size frequency curves reveal that marine clay beds of A and G subzones yield dominantly *Fagus* S-type, whereas *Fagus* in H subzone indicates L-type. *Fagus* obtained from a peat bed at Toyonaka (see Fig. 8-c) is identified with L-type. In H subzone, *Fagus* L-type is more tolerant of cold climate than *Fagus* S-type. It is difficult to determine whether the *Fagus* L-type corresponds with *Fagus crenata* or such extinct species as *Fagus microcarpa*.

The stratigraphical correlation between pollen and plant remains is shown in Fig. 9.

VII. Transition of forest and climatic change

Interpretation of spectrum

In making a deduction from the lists of plant remains it has to be assumed that the past vegetation was related to climate as it is at the present day. It is one of the basic assumptions for reconstructing the past forest. Long distance transport

Fig. 9. Stratigraphical correlation of plant remains and pollen.

"Note" LM-: Lowermost part of the Osaka group, L: Lower part of the Osaka group, U: Upper part of the Osaka group, UM: Uppermost part of the Osaka group, * Extinct species, *? Not yielded from the Osaka group but reported from the corresponding sediments in other region, ⊙: Common.

After. K. HUZITA (1954), M. ITIHARA *et al.* (1955, 1965), M. ITIHARA (1960, 1961), S. KOKAWA (1959, 1961), S. MIKI *et al.* (1962), H. NIREI (1968, 1969), K. TAKAYA & M. ITIHARA (1961), K. TAKAYA (1963), FUKAKUSA RESEARCH GROUP (1962), IBARAGI RESEARCH GROUP (1966), KINKI RESEARCH GROUP (1969), A. TAI (1963, 1964, 1965, 1966, 1969, 1970a, 1970b).

of pollen by wind and differential productivity of pollen by trees are also highly informative for evaluation of environmental reconstruction. In order to assume the climatic conditions which correspond to the forest type, the writer used correlation charts prepared from various sources (Figs. 10 a, b and Table 5).

Four groups of spectra and their corresponding climatic conditions

Spectra obtained from the Osaka group can be classified into four groups.

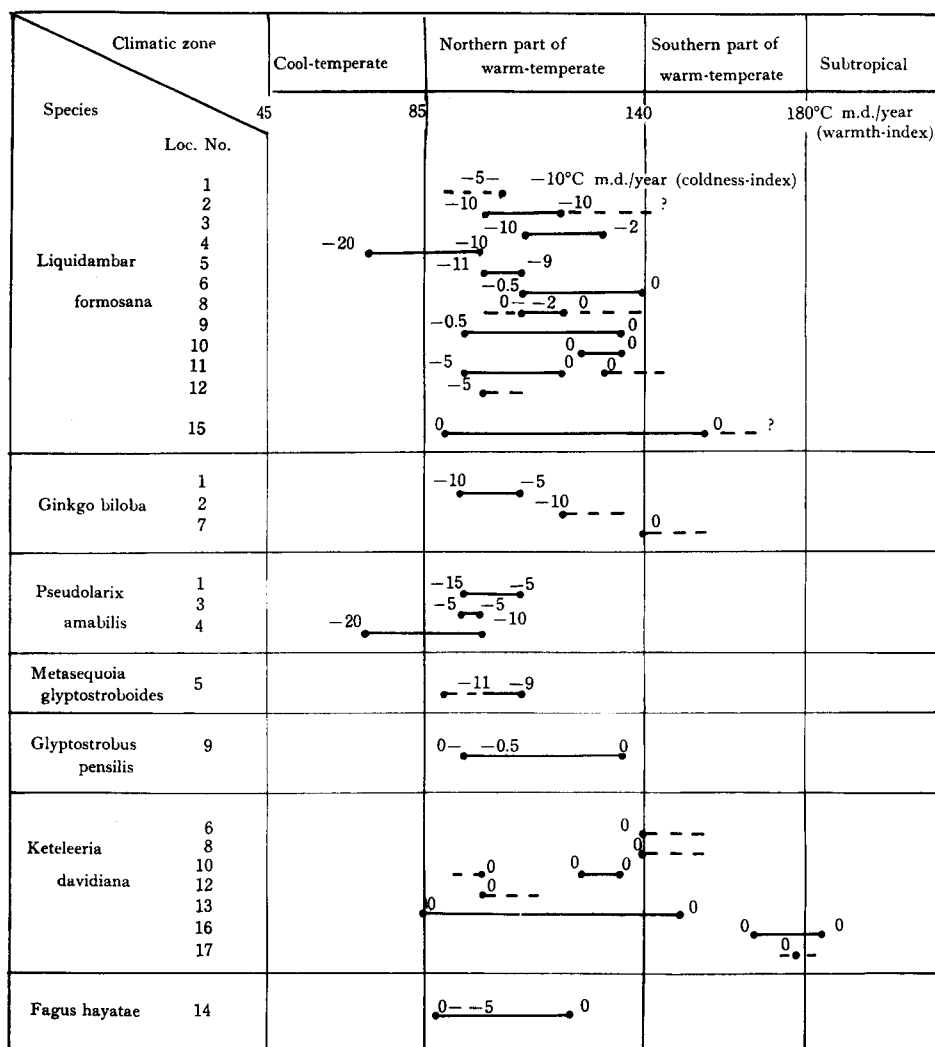


Fig. 10-a. Chart showing the temperature threshold for principal forest in China and Taiwan, compiled from the data of R. KANEHIRA (1963), LI HUI-LIN (1963) and WANG CHU-WU (1961), based on the Kira's warmth-index and coldness-index arrangement. Locality number corresponds with that of Table 5.

Table 5. Table showing the forest type and altitude of principal forests in China and Taiwan.
The data are same as in Fig. 10-a.

Locality		Forest type	Altitude
1.	Tienmu-Shan Northern Chekiang	mixed mesophytic forest	750m-1100m
2.	Hwang-Shan Southern Anhwei	"	450-1500
3.	Chiuwa-Shan Southern Anhwei	"	400- 650
4.	Lu-Shan Northern Kiangsi	"	800-1500
5.	Shusha-pa western Hupeh	deciduous broad-leaved forest	1000-1100
6.	Fanching-Shan Eastern Kweichow	"	1700-1800
7.	Lungtungkou-Hanchiakou valleys of Wuchuan-Hsien	"	1300
8.	Chenkou Western Hupen-Eastern Szechuan	desiduous broad-leaved-mesophytic forest	1200-1600
9.	Taming-Shan Southern Kwangsi	mixed mesophytic forest	1000-1700
10.	Wumong-Shan Southwestern Kweichow	evergreen broad-leaved forest	1000-2000
11.	Mon-Shan Southern Hunan	"	600-1200
12.	Taiyun-Shan Southern Fukien	"	1100
13.	Kumming Central Yunnan	pine forest	1600-2600
14.	North Chan-tien Shan (Tabboku) Northern Taiwan	evergreen broad-leaved forest	1300-1500
15.	Central part of mountainous area in Taiwan	?	900-2000
16.	Kova-Kei-Kinkaryo-kei Northern Taiwan	?	300- 600
17.	Krayu Southern Taiwan	?	900

Based on their patterns of plant assemblage the following is a brief description of each group.

(1) A group (Tertiary type flora group)

A-1 subgroup: This is characterized by such Tertiary type plants as *Keteleeria*, *Pseudolarix*, *Ginkgo*, *Liquidambar*, *Glyptostrobus* and *Sequoia*. Modern *Sequoia* is distributed along the coastal zones of northwestern North America, and the rest is alive in the mountain regions of South Middle China and Taiwan. The warmth-index* along the northern edge of the native area is around 100°C m.d. The coldness-index**calculated for *Keteleeria* and *Glyptostrobus* is 0°C m.d., and that for the rest ranges from -10°C m.d. to -15°C m.d. The climate suggested by this subgroup is very similar to that of the northern part of the warm

* T. KIRA (1945 a, b) supposing that the physiological zero point of temperature for plant is 5°C, introduced warmth-index formulated as $\sum (\theta - 5)^{\circ}\text{C month degree/year}$, where θ is average monthly temperature which is higher than 5°C.

** Coldness-index is formulated as $\sum (5 - \theta')^{\circ}\text{C month degree/year}$, where θ' is average monthly temperature which is lower than 5°C. (T. KIRA, 1948)

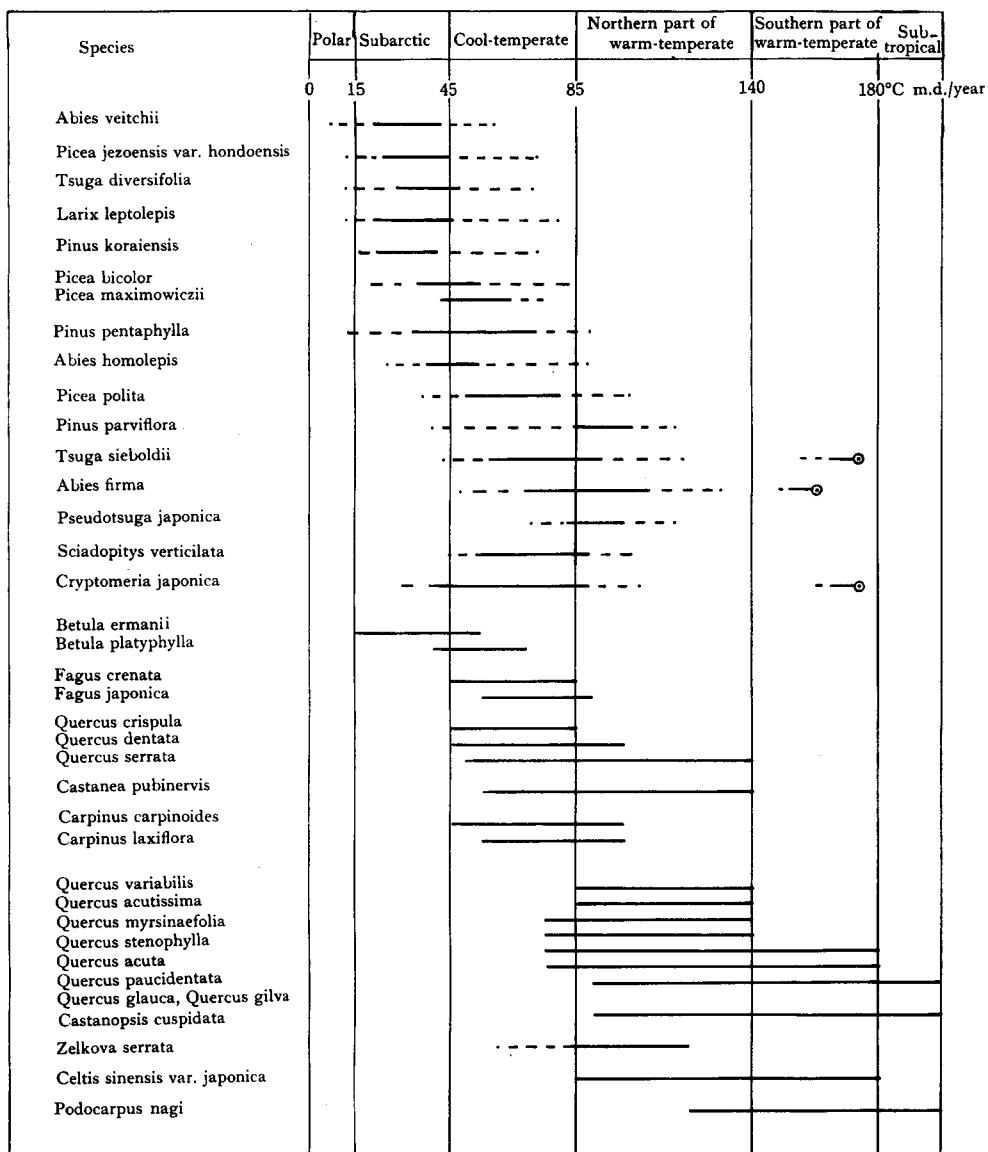


Fig. 10 b. Chart showing the temperature threshold for principal forest trees in Central part of Honshu, Japan.

"Note" with the exception of coniferous trees, mid-range of threshold temperature for tree is not visible.

—● Warm limit of the threshold temperature in Yakushima Island.

After T. KIRA (1949), 1954, 1958), T. KIRA & M. YOSHINO (1967), slightly modified by the writer.

temperate zone of the present (Fig.10-a).

A-2 subgroup: This is characterized by *Metasequoia* and *Picea* A. Native area of *Metasequoia* occupies the northern edge of the warm temperate zone, but some cultivated *Metasequoia* forests are seen beyond this limit (MACDONALD *et al.*, 1957; KIRA, 1954). This may indicate that the subgroup has the potential to extend up to the northern part of the cool temperate zone.

(2) B group (Conifer group without Tertiary type trees)

B-1 subgroup: This is characterized by *Sciadopitys*, *Tsuga sieboldii*, *Cryptomeria*, *Pseudotsuga* and *Picea polita*. The northern limit of the distribution of this subgroup lies near the border of cool temperate and subarctic zones. This means that the distribution of this subgroup is slightly warmer than that of B-2 subgroup described below (Fig. 10-b).

B-2 subgroup: This is characterized by the presence of *Picea maximowiczii*, *Picea bicolor*, *Tsuga diversifolia*, *Pinus koraiensis* and *Larix*. Their optimum zone is allocated in the areas ranging from the northern part of cool temperate zone to the southern part of the subarctic zone (Fig. 10-b). Such association as that of this subgroup is treated as the indicator of the coldest climate throughout the Osaka group.

(3) C group (Broad-leaved group)

This is characterized by *Quercus*, *Fagus* and *Zelkova-Ulmus*. The group can be classified into two categories, one with evergreen *Quercus* and the other without it. When evergreen *Quercus* is included, the climate corresponding to the vegetation is determined to be of warm temperate. But if evergreen *Quercus* absent the climatic character can not be fixed exactly. It is possible to mention only that the group has its limit around the northern edge of the cool temperate zone (Fig. 10-b).

(4) D group (Warm temperate flora group)

Such plants as *Podocarpus*, *Paliurus* and *Lagerstroemia* which flourish beyond the southern limit of the warm temperate zone are commonly found in this group.

Pattern of forest change

After the vanishing of typical Tertiary type flora, two forest types, *Metasequoia* forest and *Fagus* forest appeared. The replacement of the forest components seems to have advanced from time to time as follows.

(1) *Metasequoia* zone

a) *Metasequoia* A subzone

Plants belonging to C group occupy the bulk of this subzone. Besides the C group, such broad leaved trees as *Pterocarya*, *Juglans*, *Tilia* and *Celtis* appear consistently (TAI, 1970a) and plants of A-1 subgroup still exist in considerable high percentage. This assemblage suggests the climate of the northern part of the warm

temperate zone in which the winter climate is mild and the annual difference of temperature is relatively small. The forest of this subzone may be described as the association of deciduous broad leaved forest with evergreen broad leaved trees and the Tertiary type conifer trees.

b) *Metasequoia* B subzone

Components of A-1 subgroup decrease and those of A-2 subgroup increase. Among the C group trees, *Zelkova-Ulmus* (probably corresponding with *Zelkova ungeri*) maintains a superior position and *Quercus* appears to be wasting away more than in A subzone. Other short trees like *Sapium*, *Ilex*, *Styrax*, *Symplocos*, *Elaeagnus* predominate in this subzone (TAI, 1970-b). These facts may indicate that the summer temperature predominate in this subzone. These facts may indicate that the summer temperature is still as warm as that of A subzone.

On the other hand, Tertiary type flora such as *Keteleeria*, *Glyptostrobus* and *Sequoia* which are hardly to stand cold winter climate decline or even vanish in this subzone. This suggests that the winter climate became more severe than in the previous subzone. The climate of this subzone may be interpreted to be similar to the climate along the eastern coast of middle northern Asian continent.

In OD-1 core, *Picea* A and B (probably *Picea koribai* and *Picea maximowiczii*) become dominant at the upper part of this subzone. As the present distribution of *Picea maximowiczii* ranges from the middle to northern part of the cool temperate zone (Fig. 10-b), it can be safely said that the temperature became colder drastically towards the end of this subzone.

c) *Metasequoia* C and D subzones

As it has been known paleogeographically that there were repeated invasions of coastal environment during that period, it may be possible to interpret that the results shown in pollen diagram indicating the fluctuation of forest type depend on the degree of the oceanic environmental effects. In the C subzone, *Metasequoia* coexists with *Fagus* and *Quercus*, and some trees of the A-1 subgroup like *Ginkgo* still exist. It seems that the winter climate was still mild, although the climate as a whole was similar to that near the northern limit of the warm temperate zone. In the upper part of D subzone (Fr. 2-3), plants of B-1 and B-2 subgroups prevail and broad leaved trees are absent. *Picea* overwhelms quinquefoliate *Pinus*. This is the coldest period throughout the *Metasequoia* zone, and corresponds with the northern margin of the cool temperate zone. Ma1 and Ma2 clay beds, plants of C subgroup have the biggest share. *Metasequoia* (including *Cryptomeria*) is usually present and *Liquidambar* is also occasionally found. The climate is supposed to have been similar to that of C subzone.

When we observe the general tendency of the floral change throughout the subzone, it may be recognized, from the spectra obtained from the fresh-water deposits, that B-1 subgroup becomes increasingly dominant in the higher horizons

overwhelming the dominant components of A-2 subgroup, such as *Picea koribai* and *Metasequoia*. The replacement of A-2 subgroup by B-1 subgroup seems to have occurred just after the deposition of Ma2 clay.

All the trees except for *Cryptomeria* belonging to the B-1 subgroup, grow along the Pacific coast of the Honshu Island of Japan (HAYASHI, 1960) at present, and are considered to be tolerable to cold and dry winter. Thus D subzone is considered to indicate a cooling stage shifting from warm temperate climate to a more arctic one. Several marine clay beds with warm elements in the subzone are interpreted as the product of intermittent warmer epoche in cooling period.

(2) *Fagus* zone

Climatic oscillation and marine invasion: Climatic oscillation which began in the preceding period became distinct in this *Fagus* zone, and the whole zone can be divided into four subzones, from F to H. Each cycle of strata comprises the following three sections:

Section I C group predominating with subordinate B-1 and D group.

Section II-a C and B-1 subgroup predominant with subordinate B-2 subgroup.

Section II-b B-2 subgroup predominant.

The plants of Section I show warmer climatic condition than those of Section II. The plants of Section II-a are inhabitants in the middle to northern part of the margin the cool temperate zone (Fig. 10-b). Thus, it may be true that Section I indicates warm period and Section II indicate cold period respectively.

Every fresh-water bed situated between Ma2 and Ma9 yields the pollen assemblage of Section II, whereas every marine clay yields that of Section I. From this fact, it may be concluded that the invasion of sea water into land corresponds with the time when the climate began to be warm. In E and G subzones, transitions from Section I through II-a to I are seen. The cyclic fluctuation (II-a II-b→II-a→I section) is distinctly recognized in F subzone as well.

Forest type of cold period: A coaly clay bed at Manzidani reveals a typical floral change from the II-a type assemblage of the lower horizon to the II-b type of the upper horizon. In the lower horizon the clay yields a little *Fagus* and *Quercus* pollen but among them, the former disappear earlier than the latter. In the middle horizon the forest became open mixed forest of *Alnus* accompanied by *Corylus* and *Betula*. This open mixed forest is situated in the low-lying swampy area surrounded by hilly land with coniferous forest of *Pinus koraiensis*, *Picea bicolor*, *Picea maximowiczii*, *Tsuga diversifolia* and *Larix gmelini* (probably associated with such subarctic forest members as *Picea jezoensis* and *Abies veitchii*). During the time of the upper horizon, the coniferous forest is supposed to have extended much more extensively than in the time of the previous horizons. Thus, the whole transition seen in this coaly clay bed can be interpreted to be a process of cooling

and drying.

Pollen succession at Toyonaka shows the transition from Section I to Section II-a. High percentage of *Cryptomeria* and *Fagus* of L-type suggests cool climate having considerable annual precipitation.* This might also held in a cooling period. The floral change from C group to B-1 subgroup seen in the marine clay bed of F subzone may be transitional from a warm period to a cooler and pluvial.

Forest type of warm period: In the D and the E subzone of the marine clay beds, *Fagus* and *Quercus* (including evergreen *Quercus*) appear almost equally in number, but *Fagus* becomes more dominant than *Quercus* towards upper horizons and finally *Fagus* becomes dominant in F subzone. The climate of E subzone is postulated to have been that of the northern part of the warm temperate zone judging from the existence of evergreen *Quercus*.

The marine clay bed in G subzone is rich in *Cryptomeria* and S-type *Fagus* with occasional appearance of D group elements. Dominant *Cryptomeria* indicates that the rain fall was fairly abundant throughout the period**, and the infrequent appearance of D group elements suggests that the climate was warmer than the present (Fig. 10-b) at least during the limited time when these elements are found. Besides in a limited place like the lower part of the Ma8 at Hirakata Hill, this clay yields abundant evergreen *Quercus* (*Podocarpus* is sparsely found as shown in Fig. 2-b). The writer imagines that a secondary forest of evergreen *Quercus* might be present during this period. Similar spectrum is reported from the lowermost part of the Ma6 clay by NASU (1970).

Differentiation of the genus of *Fagus*: In the lowermost part of the Osaka group, there were four species of *Fagus* coexisting with each other in the mild climatic condition (*F. ferruginea*, *F. hayatae*, *F. japonica* and *F. microcarpa*). But in the G and H subzones *Fagus* varies from S-type to L-type. At least at the time of the G and the H subzones, *Fagus* might have been differentiated into two types, i.e., warmer temperate type and cooler temperate type.

VIII. Pollen stratigraphy and plant remains

From paleobotanical studies on the post-Miocene plant remain beds in Kinki district, Japan, MIKI (1948) proposed the following successive floral beds; *Pinus trifolia*-, *Metasequoia*-, *Paliurus*-, *Cryptomeria*-, *Larix*-, *Sapium* and *Aphananthe*- beds. In connection with this, HUZITA (1954), ITIHARA (1960, 1961), KOKAWA (1961, 1964) and ITIHARA *et al.* (1965) and many others have made stratigraphical re-

* The natural forest of *Cryptomeria*, in the western part of Honshu in Japan is distributed in regions where the annual precipitation is more than 1300 mm, and where the precipitation is less than 1,000 mm, even the cultivated *Cryptomeria* can not stand (SHIDEI *et al.*, 1957). This is true in the central part of Japan as well (TSUKADA, 1967).

**It is confirmed (KIRA & YOSHINO, 1967) that at Yakushima Island in southern Kyushu, the natural forest of *Cryptomeria* extends beyond its warmer limit of threshold temperature in Honshu.

examination concerning the deposits from which MIKI had collected samples, and the following succession has been newly confirmed.

<i>Metasequoia</i> bed	The Lower formation of the Osaka group.
<i>Paliurus</i> bed	Lower part of the Upper formation of the Osaka group.
<i>Larix gmelini</i> bed	Middle part of the Upper formation of the Osaka group. (Fr. 6-7).
<i>Syzygium</i> bed	Upper part of the Upper formation of the Osaka group (Ma8).

Metasequoia bed: As for the *Metasequoia* bed proposed originally by MIKI (1948, 1955), the date of the bed was considered to be Pliocene in age, but subsequently ITIHARA (1960, 1961) divided it into two stages, *i.e.*, that of *Metasequoia* flora flourishing age and of *Metasequoia* flora extinction age. According to ITIHARA, the transition from the former to the latter was attributable to an incursion of a cold climate, and then, this first cold epoch found in this position was provisionally handled to be the Plio-Pleistocene boundary. Later on, ITIHARA revised somewhat his idea because of a new discovery of the evidence of a cold phase at a still deeper horizon (IBARAGI RESEARCH GROUP, 1966), which is placed between yellow tuff and Shinden tuff. Now it is generally accepted that the boundary between the two *Metasequoia* floral stages, in other words, the Plio-Pleistocene boundary is considered to be in the interval between those two volcanic ashes stated above (ITIHARA and KAMEI, 1970).

Speaking of stratigraphy, both A and B subzones of the standard pollen succession correspond roughly with ITIHARA's *Metasequoia* flora flourishing age. *Metasequoia* flora flourishing age named by ITIHARA, was otherwise, called the transitional stage from the *Pinus trifolia* flora to the *Metasequoia* flora by KOKAWA (1961, 1964). *Nyssa* and *Carya* are treated as the members of this stage by KOKAWA. Regarding the pollen association of *Liquidambar-Nyssa-Carya*, SHIMAKURA (1957, 1959, 1963, 1964, 1965) deduced the conclusion that the extinction of *Nyssa* and *Carya* has preceded that of *Liquidambar*.

Concerning the information from pollen spectra, A subzone is characterized by the presence of dominant *Liquidambar*, without *Nyssa* and *Carya*. Consequently, it may be probable that the A subzone of the writer is approximately equivalent to the upper part of KOKAWA's transitional stage or to the upper part of SHIMAKURA's *Liquidambar-Nyssa-Carya* bed. As for the lower horizon lying below the A subzone, palynological studies have been made by ONISHI (1968), and ONISHI and NASU (1968), but more informative data are required in order to discuss it in more detail.

In OD-1 core, the earliest cold phase is found at the lowest horizon of C subzone, *i.e.*, the lower *Metasequoia* subzone of TAI (1966). This horizon probably coincides with the bordering part between the B and the C subzones or with the horizon intervening between the yellow tuff and the Senriyama tuff in standard

column. As mentioned before, this horizon is supposed to represent the beginning of the *Metasequoia* flora extinction age of ITIHARA.

The C subzone is dominant in *Metasequoia* pollen (Taxodiaceae I-a type pollen), whereas the D subzone is characterized by decreasing and vanishing of *Metasequoia* pollen and associated pollen of the Tertiary type flora. Taking such features into account, *Metasequoia* flora extinction age is subdivided into two, a part which bears considerable amount of *Metasequoia* pollen and a part with a small amount of *Metasequoia* pollen.

Paliurus bed: This bed is characterized by many plant remains of the vegetation of warm climate, and also by the predominance of *Fagus* pollen. According to MIKI (1948), it has been occasionally found that the *Paliurus* bed is overlain by thin layer of *Cryptomeria* bed. This change from *Paliurus* bed to *Cryptomeria* bed, in other words, the depositional sequence of warm climate to cool climate is consistent with the change of forest shown by the palynological succession from the I-section of *Fagus* to II-section. MIKI considered that the *Paliurus*-*Cryptomeria* transition was occurred only once at one horizon. But it is ascertained that such vegetational change took place not once but several times under the influence of the cyclic climatic fluctuation (Fig. 11).

Larix gmelini and *Syzygium* beds: In the Osaka group, the climatic oscillation is recognized from the lower part continuously to the upper part. *Larix* bed may be interpreted to represent the cold climax in a series of climatic fluctuation in F subzone. *Syzygium* bed which contains indicators of distinct warm climate may have a relation to such spectra which appear occasionally in the G subzone

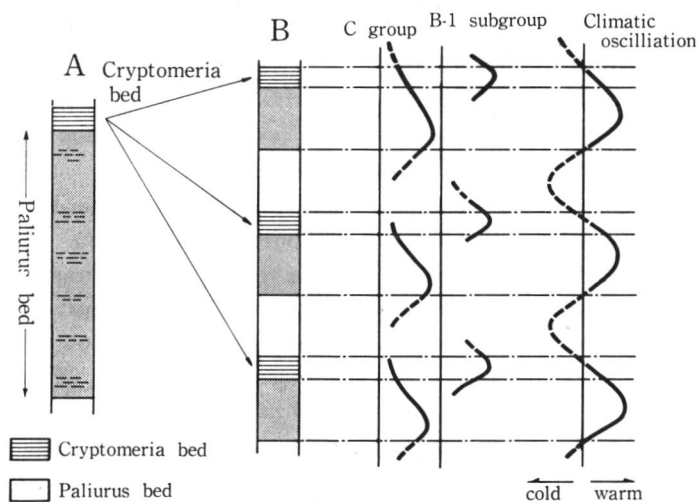


Fig. 11. Interpretation for *Paliurus* bed and *Cryptomeria* bed.
A. After S. MIKI; B. After the present writer.

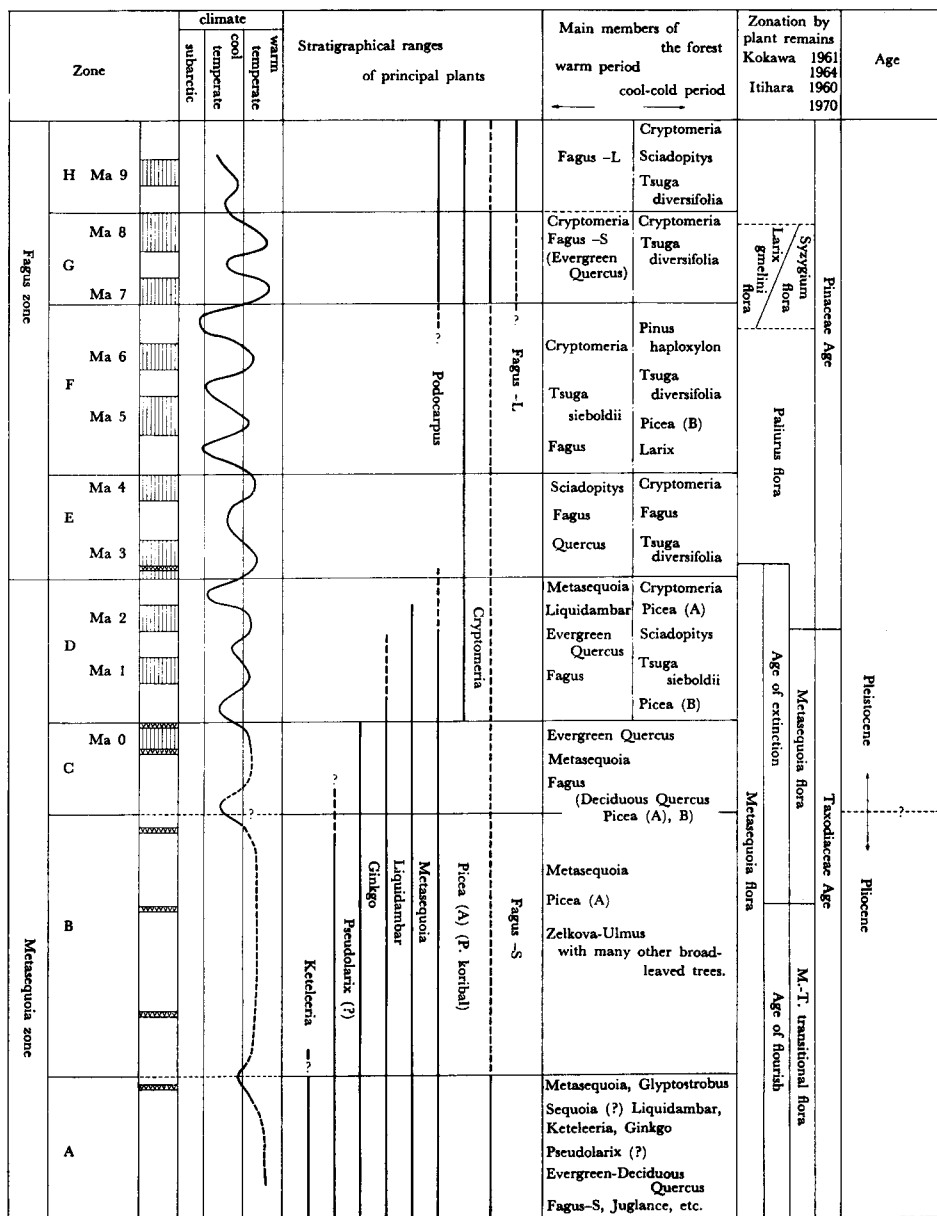


Fig. 12. Summarized chart of forest change in the Osaka group.

"Note" M.-T. transitional flora: *Metasequoia-Pinus trifolia* transitional flora, after S. KOKAWA (1961).

as the dominance of evergreen *Quercus* pollen.

It must be added that there is another problem concerning the ecological character of the vegetation of this phase. That is to say, the dominance of *Cryptomeria* and the presence of the secondary forest of evergreen *Quercus* in the G subzone. It is difficult but interesting to interpret ecologically such vegetation pattern.

The results discussed throughout this chapter is summarized in Fig. 12.

Acknowledgement

The writer wishes to express her gratitude to Associate Prof. M. ITIHARA of Osaka City University, Prof. K. NAKAZAWA, Prof. T. KAMEI, Prof. T. SHIDEI of Kyoto University and Associate Prof. S. ISHIDA of Kyoto University, Prof. M. SHIMAKURA of Nara University of Education and Prof. J. UENO of Shizuoka University for their generous direction and encouragement.

Thanks are also due to the members of the Osaka Group Research Group for their continuing interest and encouragement in the field and laboratory. This work was made possible by a helpful assistance from the Department of Geology and Mineralogy, Kyoto University, for which she expresses her appreciation.

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